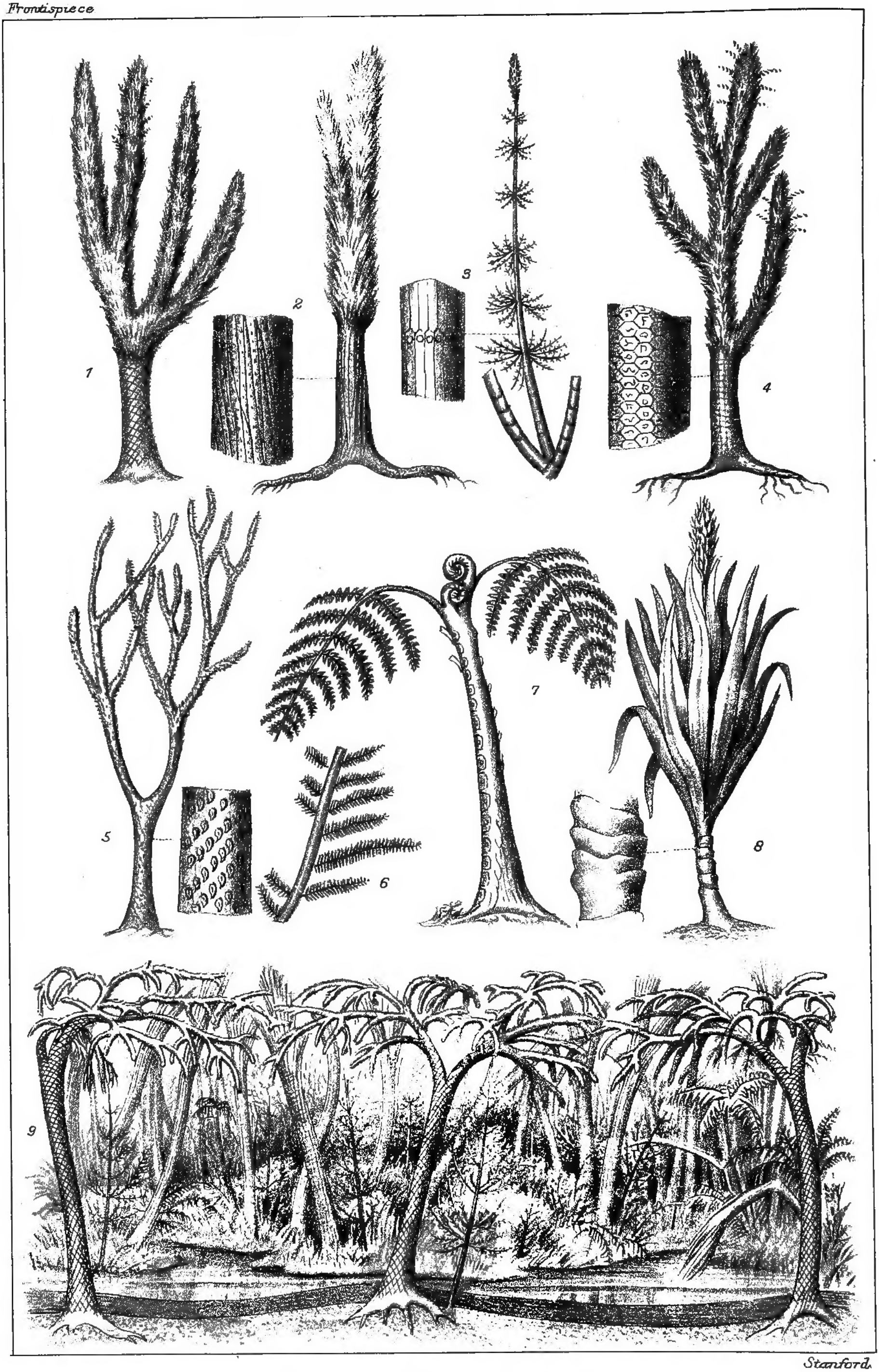
THE COAL-FIELDS OF GREAT BRITAIN.

Frontispiece



Stanford.

Plants of the Coal Period.

THE

COAL-FIELDS OF GREAT BRITAIN:

THEIR

History, Structure, and Resources.

WITH

DESCRIPTIONS OF THE COAL-FIELDS OF OUR INDIAN AND COLONIAL EMPIRE, AND OF OTHER PARTS OF THE WORLD.

BY

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Cor. Mem. Acad. Nat. Sciences of Philadelphia.

With Maps and Illustrations.

FIFTH EDITION, REVISED.

EMBODYING THE REPORTS OF THE ROYAL COAL-COMMISSION OF 1904.

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INTRODUCTORY.

OWING to the want of reliable information regarding the resources of the British coal-fields, as exhibited during the debates in Parliament on the Commercial Treaty with France in 1860, I ventured, in the following year, to bring out the first edition of this work, in which I gave estimates of the quantity of coal, both in the known coal-fields, and also beyond their visible limits down to a depth of 4,000 feet from the surface. For this undertaking I had at command both the results obtained by the Government Geological Surveyors, as also much information voluntarily tendered by friends who had personal knowledge of various coal-fields, some of which had not at that time been examined by the Government Surveyors.

In 1866, the question of the duration of our coal-supplies, and other matters dependent thereon, were entrusted for examination to a Royal Commission, consisting of gentlemen of the highest position and experience, who in 1871 issued an elaborate Report, dealing with the question of the actual quantities of coal in the visible and concealed coal-fields of the British Isles; and also with other cognate subjects, such as the probable increased rate of production,

loss and waste in working, and the possible exhaustion of our underground supplies. Prof. Jevons also, in his work entitled "The Coal Question," ably followed up similar inquiries founded avowedly upon the data furnished in an early edition of this work. Hence these important subjects, which are so intimately connected with the commercial prosperity of this kingdom, have now received very full investigation; and, I may venture to say, will at all times continue to furnish matter for discussion on the part of statesmen and political economists.

The first evidence of a decreasing supply of coal throughout the country will be a sensible rise in price; but through the agency of railways this will not become general until the resources of all the coal-fields shall have been fully developed; because, when the supply shortens in one district, a corresponding impetus will be given to mining enterprise in another, as long as the coal-seams remain unexhausted. This reciprocal process has possibly already come into operation; in illustration of which the following case may be mentioned. Many of us may live to see the southern half of the South Staffordshire coal-field exhausted, or nearly so; but while this consummation is approaching, the northern half of the same great coal-tract is far from being developed to the extent of which it is capable. The approaching exhaustion of the southern portion is already telling upon the northern.

In speaking of the exhaustion of a coal-field, I do not use the term in an absolute sense. There will always be

bands of coal, besides leavings in the coal mines, sufficient to afford a small supply to the immediate neighbourhood for domestic purposes. A coal-field may be said to be exhausted when it is necessary to import largely from neighbouring districts for manufacturing and more general purposes. From various causes, large quantities of coal have been left in old workings, much of which it will be impossible ever to recover.

I have already said that the British coal-fields can never be utterly exhausted. This is strictly true. Even disregarding the coal-beds which lie concealed beneath formations newer than those of the Carboniferous Period, there are, in some districts, coal-seams which are buried 6,000, 8,000, and perhaps 10,000 feet beneath the surface, and which, it may be presumed, can never be reached. I refer particularly to the great coal-basin of South Wales, which, as the late Mr. Vivian has shown, is capable of supplying the whole of England with coal; though for a period far shorter, I believe, than Mr. Vivian estimated. In a future page I shall enter in greater detail into this subject; and here content myself with stating the broad fact of the enormous depth of some of the coal-beds in that basin.* Now, without assigning in this place any theoretical limit to the depth at which coal may be ultimately worked, few will be disposed to deny that coal seams at the depths above

* On the authority of the late Sir H. T. de la Beche and Sir W. Logan, through whose energy the magnificent geological survey of this district is now in the hands of the public, while a newer contoured map on the 6-inch scale is in course of publication by the Geological Survey.

stated might as well be buried beneath the waters of the Atlantic, for all the probability there is of their being rendered available.

There are other districts, principally in the Midland counties, where the coal-strata dip under higher formations till they reach vast depths. For instance, there is no reason to doubt that coal underlies a portion of the plain of Cheshire, between the coal-fields of Lancashire on the north, Staffordshire on the east, and Flintshire on the west; yet, in order to reach the highest workable coal-seam under Northwich, it would be necessary to carry the shaft which reaches the great bed of rock-salt at least 4,000 feet deeper than at present.*

There are, however, very large districts in Staffordshire, Leicestershire, and Warwickshire, overspread by strata belonging to the Permian and Triassic formations, where coal may be reached at depths within 3,000 or 4,000 feet. In the north-eastern counties of Durham, Yorkshire, and Notts, there are also vast stores of fossil-fuel within reach, but overspread by formations belonging to successive geological periods. In Durham, the magnesian limestone, which attains there a thickness of 400 to 500 feet, has for several years been penetrated in various places down to the underlying coal; and the same formation, in its southerly extension into Yorkshire and Nottinghamshire, bids fair to

* It has been estimated that there are in England and Wales no less than 5,239 millions of tons of coal at a greater depth than 4,000 feet, and reaching down to 10,000 feet from the surface, where the temperature would be higher than that of boiling water.—"Report of Coal Commission" (1904).

give rise to a coal-producing district of large extent and capacity.*

The depth of many coal-shafts in the north of England is already very great. The "Arley mine" is now worked at Rose Bridge colliery, near Wigan, at a depth of 815 yards (2,445 feet).† The "cannel" seam is reached by shafts 600 yards in depth, in at least two collieries; at Pendleton colliery, near Manchester, coal is worked at a depth of 1,161 yards; at Dukinfield, in Cheshire, 686 yards.‡ The Monkwearmouth pit, near Sunderland, has a depth of 530 yards; and collieries with shafts between 400 and 500 yards are not uncommon in the coal-fields of Lancashire, Yorkshire, and Durham.§ In the Aberdare and Merthyr districts of South Wales are several deep shafts, those of Harris' Navigation Colliery being 760 and 700 yards in depth, to the "Upper Four-foot Seam."

Notwithstanding, however, all that art and industry can invent to facilitate mining at great depths, notwithstanding the increased powers of machinery and improvements in ventilation, the employment of flat wire ropes, the substitution of steel for wrought iron, and the use of two or more "lifts," or stages, at intervals from the bottom of the mine,

* See Map, p. 176.

† Appendix A; see "Brit. Assoc. Rep.," 1870, p. 30.

‡ By the extension of the workings in the coal in the direction of the dip, a depth of 918 yards below the level of the pit mouth was attained in 1880. I am informed that this colliery has been recently closed.

§ Some of the collieries in Belgium are of great depth; one of these, I am assured, reaches 932 yards, or 860 metres, and some in Saxony reach 800 yards and upwards.

we must ultimately reach a depth at which the temperature will be so high as to prohibit inexorably mining operations. What that depth may be I shall discuss in a future chapter.

The Report of the Royal Commission on Coal Reserves was signed by the Chairman and Commissioners on Saturday evening, January 7th, 1905. The labours of the Commissioners extended over a period of about three years; forty-seven meetings for the purpose of taking evidence were held, and 120 witnesses came forward to give evidence on the subjects embraced in the Terms of Reference. Most of these witnesses were nominated by mining, engineering, or other associations interested in the subject-matter entrusted to the Commission under the Royal Warrant. A vast amount of written information, bearing on cognate matters, was received from time to time in answer to written questions and applications; and maps and plans of machinery and plant were prepared by the witnesses to illustrate their statements. But for the estimates of the quantity of coal still in reserve for future use, it is gratifying to know that the owners and managers of the various holdings all over the country furnished the Commissioners with the necessary details of the quantities estimated to exist in these holdings—accompanied by maps or tracings—and arranged in tabular form according to the thickness of each seam of coal. The preparation of these returns must have often taken much valuable time, and could only have been effected when it was realised that the object was one of a public nature, and, although

not compulsory, was sanctioned by authority. Without these details, which were in all cases private and confidential, it would have been impossible to have arrived at, even approximately, definite conclusions regarding the reserves of coal in the visible or proved coal-fields; and as regards the quantities included in the concealed areas, which are of a more speculative character, and are arrived at from geological considerations, every care has been taken by the Geological Committee to keep within, rather than to over-estimate, the resources of these areas.* In dealing with these latter problems, the results arrived at by the Commissioners of 1871 were made the bases of those investigated by their successors, who had the advantage of the advance made in deep mining during the interval of 33 years, and also of the numerous borings made over the English counties either in search of coal or of water. All such borings, for whatever object, added to the sum of our knowledge of the geological structure of the districts. In all cases, the limit of 4,000 feet in depth, which was adopted by the Commission of 1871, has been adhered to as furnishing a point of comparison between the results of the two Commissions, and as being recognised as "the limit of practical depth of working"; while 1 foot was adopted as the limit of thickness for workable coal-seams.

* The Geological Committee, to which was entrusted the determination of the quantity of unworked coal in the concealed coal-areas, consisted of Mr. Teall, the Author, Professor Lapworth and Mr. Strahan. In dealing with certain districts in the east and south of England, they were assisted by Professor Boyd Dawkins and Professor Kendall.

But as it is admitted that for great depths—seams under 2 feet would be unworkable at remunerative prices—considerable reductions in quantity were made in the estimates on this ground. On the other hand, it is recognised that there is a large quantity of coal which, under favourable conditions of demand, thickness and quality, may be recoverable at depths exceeding 4,000 feet in several districts, such as Lancashire, Cheshire, and the region lying along the banks of the Trent in Lincolnshire. Time only can show to what extent these deep-seated deposits of mineral fuel can be rendered available.

In bringing out a Fifth Edition of this work, I have endeavoured to embody in it the results arrived at by the Royal Coal Commission of 1904, as far as they relate to the subject-matter of the work itself. It is not to be considered as a Report of the entire work done by the Commission, which will be found in "the Blue Books." At the same time, as the Fourth Edition had been exhausted several years ago, it was considered a favourable opportunity for bringing out a fresh edition, with the advantage of the information acquired by the proceedings of the Commission. This information will thus be more accessible to the general public than in the official form above referred to, and, it is hoped, will make the results more widely known. But it may also be stated that the proceedings of the Commission will be available in a readable form through the abstracts of the reports of evidence which have been from time to time issued in the pages of

the *Colliery Guardian*, and which, as I am informed by the Editor, will be collected and brought out in book form when completed. These reports have been embodied in a series of articles in this able journal from the commencement of the sittings of the Royal Commission, and have, doubtless, been much appreciated by the mining public.

My acknowledgments are due, and are hereby tendered to the Secretary, Mr. Charles Russell, and to several of my colleagues of the Commission, of whom I may specially mention Sir W. T. Lewis, Sir George Armytage, Mr. Arthur C. Briggs, Mr. James S. Dixon, Mr. J. J. H. Teall, (Director of the Geological Survey), and Mr. Aubrey Strahan; and I would take this opportunity of referring to a work of great value to those more directly connected with coal-mining, and abounding in details regarding the mode adopted in various collieries for dealing with the obstacles, natural and artificial, which present themselves from time to time—namely, Mr. R. L. Galloway's "Annals of Coal-Mining and the Coal Trade," in two volumes.

From amongst the numerous expressions of approval which this work has received, both from public men and from reviewers, the author is contented to select one, extracted from the speech of the late Earl of Derby (then Lord Stanley), delivered before the British Association for the Advancement of Science, at Birmingham, in 1865. Speaking on "The Coal Question," his Lordship said, "For those who desire to go more deeply into the facts of the case, as far as they are known, than is possible within

the limits of an oral address, I should recommend two books on the subject, published within the last two or three years—one by Mr. Hull, the other by Mr. Jevons. They differ somewhat widely in conclusions. The one takes what we may call the 'sanguine view' of the case, the other a view comparatively despondent; but in both one and the other you will find what is, perhaps, more important than the inferences of those authors, and that is, a very ample stock of materials upon which to found your own conclusions."—*Daily News*, September 11th, 1865.

THE COAL-FIELDS OF GREAT BRITAIN.

PART I.

CHAPTER I.

TWO ROYAL COMMISSIONS ON THE COAL RESOURCES OF THE BRITISH ISLES—AN HISTORICAL SKETCH.

IT is sufficient evidence of the importance attached by the public to the question of the resources of the British coal-fields, that within a period of 35 years two Royal Commissions have been entrusted with the task of gathering evidence and reporting on the question; and as an introduction to the matter to be discussed in this volume, it may be desirable, from an historical point of view, to place on record some of the details connected with the appointment of both Commissions. I proceed, therefore, to give some account of the persons selected by the Crown in each case, and the "terms of reference" on which they were commissioned to report.

The first Commission was appointed under the Royal Warrant of Her late Majesty Queen Victoria. The necessity for such an authoritative investigation became apparent during the debates in Parliament on the Commercial Treaty with France in 1860. Although it was

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known that the British Isles were rich in coal-deposits, their actual extent had not been proved sufficiently to give confidence that we could allow of the export of coal without imperilling our position as a manufacturing people and as a great maritime power. At that time, however, great advances had been made by the Government Geological Survey in mapping out the areas of the visible coal-fields, and in acquiring a knowledge of the extent and thickness of the seams of coal, with the aid of which estimates might be made of the available quantities remaining to be worked in each district. In like manner, our knowledge of the extent to which some of the coal-fields, especially in the northern and midland districts, disappear beneath the newer formations, with their capability of being worked to greater or less distances, was very much extended. At the same time the continuously increasing output from the collieries, a large part of which was exported to foreign countries, gave rise to increased anxiety; and at length, in 1866, a Royal Commission, presided over by the late Duke of Argyll, was appointed for the purpose of investigating "The probable quantity of coal contained in the coal-fields of the United Kingdom, and to report on the quantity of such coal which may be reasonably expected to be available for use." Other cognate subjects were included in "the Terms of Reference," but the former were the more important, and are those which most concern us in this place. The Commissioners were gentlemen of high standing, either as geologists or as being connected with the coal industry; and besides the President, the Commission consisted of Sir Roderick I. Murchison, Mr. Robert Hunt, Prof. J. Beete Jukes, Prof. (afterward Sir) Joseph Prestwich, Sir Andrew C. Ramsay, Sir George Elliot,

Mr. John Geddes, Sir William Armstrong, Mr. Joseph Dickinson, Mr. John T. Woodhouse, Mr. G. T. Clark, and Mr. Hussey H. Vivian. After numerous sittings, and having heard much evidence, the Commission issued its report in 1871, to the effect that within a limit of 4,000 feet below the surface there existed 146,480 millions of tons of coal available for future use; in this estimate, seams between one and two feet were included.

The approximate limit of 4,000 feet above stated was that adopted by the author in the first edition of this work, published in 1860, several years before the appointment of the Royal Commission of 1871, on the grounds both of temperature and pressure; and is that which has been adhered to by the Commission of 1904, in order that a general comparison might be made between the estimates of the latter Commission and those of its predecessor.* At the same time it is recognised that in some districts of the midland and northern counties, beds of coal lie buried at depths exceeding this adopted limit; but whether, and to what extent, they may be ultimately recoverable is a problem which must be left to future generations to solve. That 4,000 feet has been proved to be a judicious basis for the calculation of available quantities of coal is shown by the fact that down to the present time it has not been exceeded in any of the coal-mines of the British Isles now in operation; there are, indeed, certain coal-fields in which this limit cannot be reached or exceeded, owing to the fact that the coal-strata are not of sufficient thickness to admit of mining operations in those districts.

At the date on which the first Commission concluded its estimate of resources (1870) the production of British coal

* "First Report," p. 7 (August, 1903).

amounted to 110,431,192 tons,* but with only a few occasional relapses in the rate of increase,† the output in 1901 was about double that of 1870. To use a well-known phrase, the increase has gone on "by leaps and bounds," and now reaches over 230 millions of tons.‡ For whatever length of time, therefore, the estimated quantity might have lasted if the output had remained stationary at the amount it had reached in 1866, that length of time would have been reduced by one-half at the close of the last century. This somewhat alarming result was probably the chief reason for the pressure which was brought to bear on the Ministry of Mr. Balfour, to induce him to recommend to His Majesty King Edward VII. the appointment of a second Commission for the purpose of taking evidence and reporting on subjects of a character somewhat similar to those which were entrusted to its predecessor.

The selection of Members to serve on the Commission of 1901 was entrusted to the Rt. Hon. Sir Michael Hicks Beach, Chancellor of the Exchequer,§ and consisted of the following: The Rt. Hon. William L. Jackson, M.P. (afterwards Lord Allerton), Sir George J. Armytage, Bart., Sir William T. Lewis, Bart., Sir Lindsay Wood, Bart., Mr. Thomas Bell, Mr. William Brace, Mr. Arthur C. Briggs, Prof. Harold B. Dixon, Mr. James S. Dixon, Sir Clement Le Neve Foster,‖ Prof. Edward Hull, Prof. Charles Lapworth,

* "Mineral Statistics United Kingdom for 1895 (1896)."

† Especially those of 1874, 1878, 1884, 1886, and 1893.

‡ "Board of Trade Returns (Coal Tables), 1904."

§ The Royal Warrant, dated December 28, 1901, is signed by Mr. Charles T. Ritchie, Secretary to the Board of Trade.

‖ To the great regret of all his colleagues, Prof. Sir C. Le N. Foster died during the session of the Commission, and Mr. Aubrey Strahan, F.R.S., of the Geological Survey, was appointed to serve in his stead.

Mr. Joseph P. Maclay, Mr. Arthur Sopwith, Mr. J. J. H. Teall, Director of the Geological Survey, and Mr. Ralph Young; Mr. W. Russell, Barrister-at-Law, was appointed Secretary. The "Terms of Reference" included inquiry into the extent and available resources of the coal-fields of the United Kingdom; the rate of exhaustion which may be anticipated, having regard to possible economies in use by the substitution of other fuel, or the adoption of other kinds of power; the effect of our exports of coal on the home supply; and the time for which that supply, especially of the more valuable kinds of coal, will be available to British consumers, including the Royal Navy, at a cost which would not be detrimental to the general welfare; the possibility of a reduction in that cost, by cheaper transport, or by the avoidance of unnecessary waste in working through the adoption of better methods and improved appliances or through a change in the customary term and provisions of mineral leases; and lastly, whether the mining industry of this country under existing conditions is maintaining its competitive power with the coal-fields of other countries.

The above Terms of Reference will appear at first sight excessively wide, but are capable of being included in the five following clauses:—

1. Enquiry into extent and resources of the fields, visible and concealed.
2. Future rate of exhaustion of coal supplies.
3. Effect of export in coal on various home industries, including the Royal Navy.
4. Possible reduction of cost in coal by improved methods of working and cheaper transport.
5. Comparison of the state of British and Foreign mining industries.

Of the above clauses the first was evidently the most important; and, in fact, constituted the basis for the proper treatment of those which follow. It was necessary that a fresh investigation should be made of the resources of all the coal-producing districts of the Kingdom, and adjoining areas, on which much new light had been thrown by the general advance of coal-mining since 1871, and by experiments through boring operations carried out in many places by companies, or private individuals, within the last quarter of a century.

For the purpose, therefore, of ascertaining the available coal-resources, the Commissioners proceeded to group the known coal-fields into districts, and to place each district in the charge of one or more members of the Commission. Seven districts were agreed upon, and the following Commissioners were placed in charge of them.*

District A.—South Wales, Monmouthshire, Forest-of-Dean, Bristol, and Somersetshire.	Sir William T. Lewis.
District B.—Staffordshire, Warwickshire, Leicestershire, Shropshire, and South Derbyshire.	Prof. Lapworth and Mr. Sopwith.
District C.—North Wales, Lancashire, and Cheshire	Prof. Hull, Dr. Le Neve Foster, and Sir George Armytage.†
District D.—Yorkshire, Derbyshire, and Nottinghamshire.	Mr. A. Currer Briggs.
District E.—Durham, Northumberland, Cumberland, and Westmorland.	Sir Lindsay Wood.
District F.—Scotland	Mr. J. S. Dixon.
District G.—Ireland	Prof. Hull.

Each District Commissioner was authorised to obtain

* "First Report," vol. i (1903).

† On the death of Sir C. Le Neve Foster, North Wales was put under the charge of Mr. Aubrey Strahan, who was appointed a member of the Commission.

the assistance of mining engineers of local experience in order to collect and tabulate returns from the various collieries; and though at the outset some colliery owners were unwilling, for various reasons, to supply the information asked for, yet, when subsequently opportunity was afforded for discussing the matter with them, and of explaining the object and purposes of the enquiry, this difficulty was largely overcome, and it may be said that very little information of value has been withheld. We may, therefore, feel confidence in the conclusions arrived at, owing to the care taken by the Commissioners and their assistants in their preparation; though some doubt may be entertained whether it was wise to include seams of coal of less thickness than two feet in the estimates of quantities.*

THE GEOLOGICAL COMMITTEE.—For the purpose of considering the important subject of the extension of the coal-bearing strata below the newer Secondary formations in the centre and south of England, a small Committee of Commissioners, chiefly geologists, was appointed. The subject entrusted to them was of a technical character, dependent on conclusions regarding the distribution of strata below and above the Carboniferous formations. It had been very fully dealt with by Sir Joseph Prestwich, Sir A. C. Ramsay, and the author in the Report of 1871; but as from that period to the present many experiments, both by shafts and borings, had been made, some of which tended to confirm, or otherwise, the views arrived at, it was

* The author has always held that it would have been safer to have made the limit of thickness for deep workings of seams two feet instead of one, but as the Commissioners of 1871 had adopted the latter, it was considered better, for purposes of comparison, to adhere to this determination.

desirable that a fresh examination of the question should be made. Particularly was this desirable as regards the district south of the Thames Valley, where an experimental boring carried down to a depth of 2,177 feet, under the superintendence of Mr. Francis Brady, C.E., in 1895–6, was successful in proving the existence of coal-strata below the Chalk near Dover. We shall return to this important discovery later on, as it indicates the existence of a band of coal-measures in a tract where a few years ago the idea would have seemed incredible. Another discovery of a somewhat similarly unlooked for character is that of coal under the Oolitic strata of Oxfordshire, near Burford, though this experiment was carried out somewhat earlier than the former, namely, in 1877.

Such is a brief historical sketch of the origin and proceedings of these two Royal Commissions; nor does any apology appear necessary for introducing the subject here, when we consider the importance of the problems entrusted to the members of the Commissions, and the time and labour devoted to their solution, both by themselves and by the many witnesses who came forward to give evidence on the subjects of which they had special knowledge and experience; nor should I omit to state that in all cases the time and labour thus bestowed was gratuitous, and voluntary on the part both of the Commissioners and of the gentlemen who came forward to give evidence, and who, in nearly all, if not absolutely all, cases had special duties to perform in their various walks of life of an important nature. I think it right to make this statement, because it has been supposed in some quarters that the Commissioners and witnesses have been paid by the State for their time and services. Such was not the case.

Before, however, entering on the enquiry regarding the extent and resources of our coal-fields, it may be desirable to give some account regarding the formation of beds of coal and the remains of animals and plants which are enclosed in their strata. With these introductory statements the reader will be better able to understand the succeeding parts of the book.

Formation of Coal-strata.—Little need be said here on this subject, partly because the mode of formation of coal-seams, and the strata in which they are found, is so generally known; and the subject is itself dealt with in the chapter describing the formation of coal-fields;* we may therefore pass on to the consideration of the animals and plants whose remains are found associated with the beds of coal, and which tend to throw light on the fauna and flora of the coal-period.

* Chap. iv, p. 30.

CHAPTER II.

THE ANIMAL REMAINS OF THE COAL-PERIOD.

THE animal life of the Coal-period is represented by Reptiles (*Labyrinthodont Amphibia*), Fishes, Insects, Crustaceans, Annelides, and Molluscs.

REPTILES.—The remains of these have been obtained from the South Joggins Coal-field of Nova Scotia;* from the Castlecomer Coal-field in Ireland;† from the Edinburgh Coal-field; from that of Münster-Appel in Rhenish Bavaria,‡ and from Saarbrück in Rhenish Prussia. Reptilian life appears to have been only locally abundant, and entirely absent from many coal-bearing regions.

The principal genera are *Anthracosaurus*, *Apateon*, *Archegosaurus*, *Campylopleuron*, *Dendrerpeton*, *Dolichosoma*, *Hylonomus*, *Keraterpeton*, *Loxomma*, *Ophiderpeton*, and *Urocordylus*.

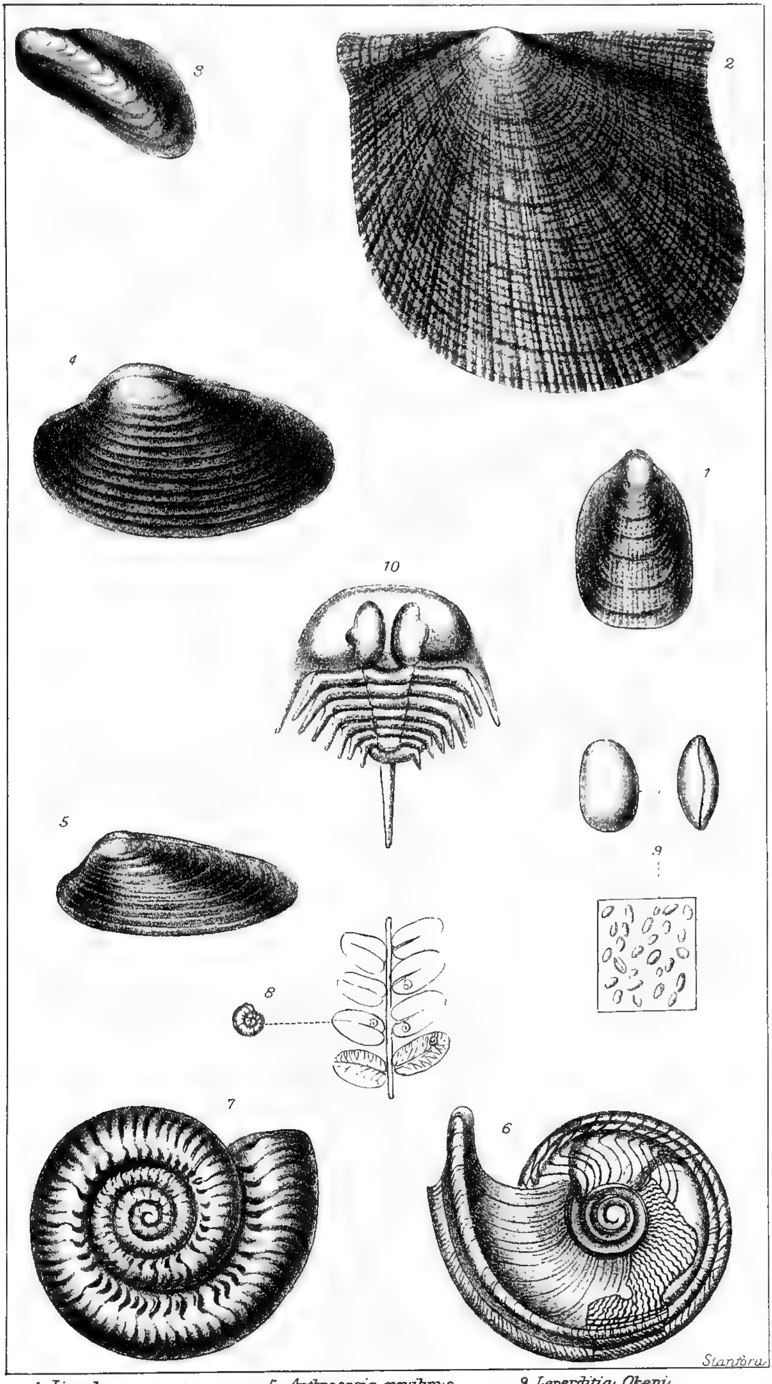
FISHES.—The fishes were abundant; their remains, generally confined to teeth or scales, being found in great numbers on the upper surface of the beds of coal, or in the dark shales which in most cases form the roof of the coal-seams. They all belong to the "heterocercal type," and were probably migratory in their habits, frequenting the open sea, as well as the estuaries, lakes, and lagoons of

* Dawson, "Quart. Journ. Geol. Soc.," vol. xviii.

† Huxley and Wright, "Trans. Roy. Irish Acad.," vol. xxiv.

‡ H. von Meyer, quoted by Lyell, "Man. of Geol.," 5th edit., p. 400.

CHARACTERISTIC FOSSILS OF THE COAL FORMATION.



1 *Lingula squamosa*
2 *Aviculopecten papyraceus*
3. *Anthracomya carinata*
4 *Anthracosia centralis*
5 *Anthracosia æquilinus.*
6 *Goniatites bilinguis.*
7. *Goniatites Listeri*
8 *Spirorbis caperatus.* *(on Pecopteris)*
9. *Leperditia Okeni var Scoto-burdigalensis*
10. *Belinurus trilobitoides*

the coal period. The principal genera are:—*Acanthodus*, *Cladodus*, *Cochliodus*, *Cœlacanthus*, *Ctenacanthus*, *Diplodus*, *Gyrolepus*, *Holoptychius*, *Megalichthys*, *Orodus*, *Palæoniscus*, *Platysomus*, *Pœcilodus*, *Psammodus* and *Rhizodus*.

INSECTS, SPIDERS, and MYRIAPODS.—The remains of insects have been found in the coal-measures of Europe, the British Isles, and America. They include examples of *Blattina*, *Neuroptera*, *Scarabæus*, besides *Arachnida* and *Myriapoda*.* The coal-measures of Coalbrook Dale, in Shropshire, have afforded several examples, as well as those of the Saarbrück district, where they are preserved in the nodules of clay-ironstone.† The scarcity of specimens of insects is not to be considered as indicating that insect life was not prolific during the coal-period; on the contrary, considering the perishable nature of the whole animal—except in the case of the elytra of beetles—the wonder is that so many varieties and specimens have been found; and it is very probable that the warm and equable temperature of the coal-period stimulated insect-life to a high extent amongst the moist, shady lagoons and dense forests which overspread such a large portion of the earth's surface.

CRUSTACEANS.—The coal-period appears to have witnessed the extinction of the great family of the trilobites, whose remains are found in such numbers amongst the Silurian Rocks. Specimens of the genus *Phillipsia* have been discovered amongst the shales of the Lower Coal-measures of Kilkenny,‡ and in a similar position in

* The *Arachnida* and *Myriapoda* have been separated from the true insects by Prof. Huxley.

† Described by Fr. Goldenberg, "Palæont.: Dunker u. H. v. Meyer." Vol. iv.

‡ "Quart. Journ. Geol. Soc.," November, 1877, p. 621.

Silesia.* Specimens of crustaceans allied to the king crab have been discovered in the coal-measures of Coalbrook Dale, and in Carlow or Queen's County. The former have been referred by Prof. Prestwich to the genus *Limulus*,† the latter to that of *Bellinurus*, of which two species are described by Mr. W. H. Baily.‡ The marine habits of these crustaceans is a sufficient reason for their scarcity in the Middle and Upper Coal-measures, which were essentially of fresh-water origin. Entomostraca, however, are very abundant in the shales of the Lower Coal-formation of Scotland and elsewhere.

ANNELIDES were represented by *Spirorbis carbonarius*, which is abundant in the shales of the Lower Coal-measures of Britain, and in the limestones of the Upper Coal-measures of Lancashire.§ It is often found adhering to marine shells, as well as to the fronds of ferns and stems of plants, and was probably an inhabitant of estuaries as well as of inland lakes.

MOLLUSCS.—The Molluscs (together with the *Molluscoida*) are very fully represented in the Coal-measures of the British Isles, Europe, and America. Many of the species, and all the genera, survive from the seas of the Carboniferous Limestone period.

The vertical range of these marine forms became a subject of interesting investigation to myself some years ago, and has been discussed in a paper read before the

* F. Roemer, "Zeitschr. d. deuts. geolog. Gesellsch.," 1863.

† "Geol. Trans.," 2nd series, vol. v, p. 440.

‡ Explanation to sheet 137 of the Maps of the Geological Survey of Ireland, p. 12. A figure of *B. trilobitoides* will be found in the Plate of Characteristic Fossils.

§ *Ibid.* The affinities and habits of this annelide are ably discussed by Mr. R. Etheridge, Jun., in the "Geological Magazine," May, 1880.

Geological Society of London.* I found that out of 36 genera and about 70 species of truly marine forms known to occur in the Lower Coal-measures or "Gannister Beds," only six species pass upwards into the Middle and Upper Coal-measures, which are characterized by bivalve shells of the genera *Anthracosia* and *Anthracomya*, of whose habits we possess but little knowledge. A census of the genera and species, including *Cephalopods*, *Heteropods*, *Gasteropods*, *Conchifera*, and *Brachiopods*, collected from the Lower Coal-measures (or "Gannister Beds") of the British Isles and the West of Europe, shows conclusively that this formation, like those of the Millstone Grit, Yoredale Beds, and Carboniferous Limestone, was essentially of marine origin, and ought to be separated from the Middle and Upper Coal-measures in any future system of classification. To this question I shall have occasion to return, and only now mention the names of the principal genera and species of the Lower, Middle, and Upper Coal-measures.

LOWER COAL-MEASURES (" *Gannister Beds* ").

(*Marine.*)

CRUSTACEA.—Phillipsia pustulata (*Schloth.*), Leperditia Okeni (*Nünst.*).

CEPHALOPODA.—Goniatites fasciculatus (*M'Coy*), G. crenistria (*Phil.*), G. Listeri (*Mart.*), G. Gibsoni (*Phil.*), G. Looneyi (*Phil.*), G. reticulatus (*Phil.*). Nautilus armatus (*Sow.*), N. concavus (*Sow.*), N. clitellarius, N. falcatus (*Sow.*), etc., Orthoceras Steinhaueri (*Sow.*), O. scalpratum (*Prestw.*).

PTEROPODA.—Bellerophon apertus (*Sow.*), B. decussatus (*Flem.*), B. hiulcus (*Sow.*), B. navicula (*Sow.*), Conularia quadrisulcata (*Sow.*).

GASTEROPODA.—Euomphalus, Littorina (?), Macrocheilus fusiformis (*Sow.*), Pleuratomaria limbata (*Phil.*).

* "On the Upper Limit of the essentially Marine Beds of the Carboniferous Group, etc.," "Journ. Geol. Soc.," November, 1877, p. 613.

CONCHIFERA.—Arca, Aviculo-pecten scalaris (*Sow.*), A. gentilis (*Sow.*), A. papyraceus (*Goldf.*), A. alternans (*M'Coy*), A. variabilis (*M'Coy*), Avicula quadrata (*M'Coy*), A. modiolaris, Axinus sulcatus (*Sow.*), Ctenodonta undulata (*Phil.*), Ct. gibbosa (*Flem.*), Ct. æquilis (*Sow.*), Edmondia unioformis (*Phil.*), Myacites sulcatus (*Flem.*), Myalina triangularis (*Sow.*), Pullastra bistriata (*Portl.*), P. scalaris (*M'Coy*), Monotis lævis (*Brown*), Posidonomya Gibsoni (*Brown*), P. lævigata (*Brown*), P. Becheri (*Goldf.*), Schizodus sulcatus (*Sow.*), S. Carbonarius (*Portl.*)

BRACHIOPODA.—Athyris planosculata (*Phil.*), Chonetes Hardrensis (*Phil.*), Discina nitida (*Phil.*), Edmondia, Lingula mytiloides (*Sow.*), Orthis resupinata (*Mart.*), Productus semireticularis (*Mart.*), P. concinnus (*Sow.*), P. scabriculus (*Mart.*), P. hemisphæricus (*Sow.*), Rhynchonella pleurodon (*Phil.*), Spirifera Urii (*Flem.*), S. glabra (*Sow.*), S. bisulcata (*Sow.*), S. pinguis (*Sow.*), S. semireticularis (*Phil.*).

ECHINODERMATA.—Archæocidaris (?), Actinocrinus, Cyathocrinites quinquangularis (*Miller*).

MIDDLE AND UPPER COAL-MEASURES.

(*Estuarine and Lacustrine.*)

The Middle and Upper Coal-measures are characterized by a few forms of bivalves (Conchifera) belonging to the genera *Anthracosia* (Unio), *Anthracomya* and *Anthracoptera*, capable, apparently, of living in fresh water lakes or brackish-water estuaries. At rare intervals, during the deposition of the beds of these stages, the waters of the sea overflowed, bringing with them marine forms, so that we find, as in the cases of the "Bay-coal bass" of Staffordshire, the "Chance-Pennystone" of Coalbrook Dale, and the remarkable bed lying at the top of the Middle Coal-measures of Ashton-under-Lyne,* occasional marine bands amongst vast masses of fresh water strata. With

* Discovered by the late Prof. A. H. Green; see "Geology of Oldham," Mem. Geol. Survey.

the above exceptions, the Middle and Upper Coal-measures appear to have been deposited under conditions differing from those which prevailed previously, as shown by the general absence of those marine forms which are so prevalent in the subordinate beds.*

Very interesting is the discovery of the shells of air-breathing snails, which have been found in considerable numbers in the trunks of trees, in the South Joggins Coal-field, by the late Sir W. Dawson, and more recently in England. *Helix priscus* and *Pupa vetusta* are probably only the representatives of numerous species of the pulminiferous gasteropods of the coal-period.

Tracks of burrowing Annelides, as well as occasionally those of Molluscs and Crustaceans, are common on the surfaces of the flagstones of the Carboniferous beds, whose intertidal and estuarine habitats are indicated by the occurrence in the same strata of rain pits and sun cracks, such as those described by Sir C. Lyell from the Cape Breton coal district.† Another form of Annelide, *Spirorbis Carbonarius*, has already been described.

* For fuller information see author's paper already referred to, *supra*, p. 13.

† Observed by Mr. Richard Brown, "Manual of Elem. Geology," 5th edit., p. 384.

CHAPTER III.

THE PLANT REMAINS OF THE CARBONIFEROUS PERIOD.

(*Revised by the late Professor Williamson, F.R.S.*)

THE vegetable origin of coal was recognised as far back as 1785 by the philosopher Hutton,* and is demonstrable, not only by its microscopic structure, its combustible properties and chemical composition, but also by certain phenomena which may generally be observed in reference to its position in the strata.

Of the two theories of the formation of coal, the first, which refers its origin to drift-wood carried down by streams, and imbedded in estuaries, is certainly inapplicable to the vast majority of coal-seams; the second, according to which the vegetable materials grew on the spot where we now find them in the form of coal, is the only one which is in harmony with the phenomena which generally present themselves amongst British coal-measures.

The subject will be more intelligible to the reader if he becomes in some degree familiar with a few of the leading members of that luxuriant flora which flourished in the Carboniferous period.

That we have only fragmentary examples of the plants of this period must be evident; for although vegetation

* James Hutton, "Theory of the Earth," "Trans. Roy. Soc. Edinburgh," 1785.

attained a luxuriance which has never before or since been equalled, yet the number of species of coal-plants as yet determined is only about one-twentieth of that of living plants now growing over Europe alone. The number of species noticed by Adolphe Brongniart was 500, which are classified as follows :—*

Thallogens = Cellular cryptogams	...	6 species.
Acrogens = Vascular ,,	...	346 ,,
Gymnosperms	..	135 ,,
Doubtful	..	13 ,,

This number has since been increased by Prof. Göppert, who estimates the known species of fossil plants of the Carboniferous period to be 879; these he classifies as follows :—

CELLULARES, including Fungi, Algæ, etc., 13 species.

VASCULARES, 866 species, of which 772 are *Cryptogams*, or Ferns, Calamites, Lepidodendra, Sigillariæ, etc.; and 94 are *Phanerogams*, such as Conifers, etc.

It must be borne in mind, however, that but little reliance can be placed upon these figures, since very few of the recognised species can be accepted as accurately determined.

The cellular Cryptogams are few in number, and of doubtful character; the great majority of the fossil plants of this period belong therefore to the vascular Cryptogamic class; the gymnosperm Phanerogams and Coniferæ are also represented in the Carboniferous flora, but by a much smaller proportion of species.

The perishable nature of plants under moisture, or water, is perhaps the principal cause of the fewness of the

* "Histoire des Végetaux Fossiles" (Appendix D).

species preserved. It is probable, however, that individuals of a few species predominated very largely, as is the case now in our pine forests, and in the great cypress swamps at the mouth of the Mississippi. Dr. Lindley, by a very interesting experiment, thought that he had arrived at a clue to account for the large predominance of certain classes of plants amongst those which have been preserved. By immersing in cold water for two years a large number of plants, as nearly as possible representatives of those of the coal-measures, he obtained the following results:—He found that the dicotyledonous plants are in general incapable of resisting decomposition when immersed for two years, with the exception of the Coniferæ. Secondly, that monocotyledonous plants are less liable to decomposition, but that grasses and sedges perish rapidly. Thirdly, that fungi, mosses, and equisetums disappear, while ferns have a great power of endurance, the effect of immersion being only *to destroy all traces of fructification;* a satisfactory reason why fossil-ferns seldom present this portion of their structure, though the fronds themselves occur in great numbers, and in admirable preservation.*

There appears to have been a uniformity in the vegetation of the coal period, to which there is now no parallel. The same genera, and many of the same species, ranged throughout the whole of Europe, and of North America from the Arctic regions as far south as the 30th parallel, that is to say, over a space comprehending about 45 degrees of latitude; and this uniformity of vegetation is continued vertically, for we find the same species ranging throughout the whole series of strata, sometimes amounting to a thickness of at least 14,000 feet.

* Lindley and Hutton, "Fossil Flora," vol. iii.

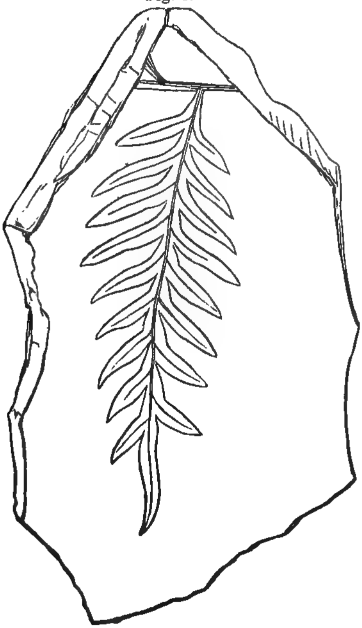
But perhaps the most inexplicable phenomenon in connection with this subject is the occurrence of coal and Carboniferous plants in the Arctic regions. They have been brought from Melville Island, in latitude 76 degrees. Specimens of coal, fossil-wood, and shells belonging to Carboniferous types have been brought to this country by Sir E. Belcher from Albert Land, in latitude 78 degrees of the western hemisphere, and by Mr. Lamont from Spitzbergen, in about the same parallel in the eastern, where the country is described as frightfully barren and desolate, and entirely destitute of vegetation, with the exception of saxifrages, reindeer moss, and similar dwarfish plants. Reasoning from analogy, we could never have supposed that in latitudes now subject to the severest frosts throughout the greater part of the year, and even to deprivation of light for a long period, a vegetation could have flourished allied to that of the tropics, or at least to that of the warmer temperate zones of the present day. But recent investigations have shown that even in the Miocene Age the same regions developed a vegetation like that of our warmer and temperate regions. In many respects the Carboniferous period was certainly a remarkable one, especially in the almost universal diffusion of such plants as Calamites, Sigillaria and Lepidodendron. From all this it would appear that the climate resembled one in which the temperature was free from extremes, rather than that of the equatorial regions.

Of the plants that are commonly preserved to us, the ferns seem to take the lowest rank, and the coniferæ the highest; *Calamites*, *Sigillaria* and *Lepidodendon* occupying intermediate positions.* The ferns constituted a most

* Sir J. D. Hooker, "On the Vegetation of the Carboniferous Period,"

prolific class, occurring in vast quantities in the shales which overlie the coal-seams. The Sigillariæ, Lepidodendra, and Calamites appear to have formed the greater mass of coal; and the roots of the two former (Stigmariæ) penetrate in vast quantities the underclays or floors of the coal-seams. Coniferous trees, however, formed at some localities a considerable portion of the mass of the coal; but they seem to have grown on higher and dryer ground than that on which the more characteristic plants above mentioned flourished. The following is a short description of the genera which have been most prolific and characteristic amongst the flora of this ancient period.

Fig. 1.



Alethopteris lonchitica.
Portion of frond; two-thirds nat. size. From a specimen in the Natural History Museum, Manchester.

FERNS.—These form a very large proportion of the Carboniferous flora; and, with the exception of their fructification, which has almost

"Mem. Geol. Survey," vol. ii, p. 395. See also "Lectures on the Fossil Plants of the Coal-measures," by Prof. W. C. Williamson, F.R.S., "Proc. Roy. Soc.," vol. xxvi, p. 411 (1877), and "Observations on the Structure of Fossil Plants of Carboniferous Strata," by E. W. Binney, F.R.S., Palæont. Soc., 1867–72, Parts i, ii, and iii.

always disappeared, are preserved in great perfection. Some of them are represented at the present day by the aborescent forms of the tropics, which flourish in Ceylon, the islands of the Pacific, and the Indian Archipelago, where they are so abundant as to equal in numbers the whole of the phanerogamic plants.

The most abundant species in British Coal-measures are: *Alethopteris* and *Pecopteris.** Of the 140 supposed species known in Britain, 50 occur in the same formation in North America, some ranging from Nova Scotia as far south as latitude 35 degrees.† It is, however, to be remarked that we know little of the habits of the ferns of the coal-period, whether they grew out of the ground, or were parasitic on the trunks of trees; and it is even extremely uncertain what proportion of the large assemblage of fronds belonged to tree-ferns, as we never find the fronds attached to their stems; and the stems themselves are of extreme rarity.

CALAMITES.—This is an abundant genus, and was considered by Brongniart to be represented in our day by the *Equisetaceæ*, of which the horse-tail of our swamps and ponds is a familiar example. Many continental botanists believe that these plants were Gymnosperms; but there is much reason for accepting Brongniart's conclusion, though it is equally certain that whilst the common specimens are merely inorganic casts of a hollow fistular medullary cavity, this medulla was invested by an exogenous vascular zone, enclosed within a rather compli-

* I omit Cyclopteris, as it is still uncertain whether it belongs to the fern tribe. Mr. Salter believed it to be the leaf of a conifer. See "Geologist," vol. iii.

† Hooker, *ibid.*, *supra cit.*, p. 52.

cated bark, the two latter structures having often attained to considerable thickness. When young they gave off verticils or twigs, but at a more advanced growth only a small number of these developed into large unsymmetrical branches. The leaves appear also to have been verticillate, but they are difficult of identification ; very different plants being included in the genera termed Calamites, Sphenophyllum and Asterophyllites. But little is known of the fructification of Calamites.

This family extends from Lapland to the Equator, attaining the greatest number of species in the temperate zone. The fossil genera differ from the recent in the absence of the encircling sheaths at the joints. The Calamites frequently attain a length of twenty feet.

SIGILLARIA AND LEPIDODENDRON.—These two genera are believed by all British Palæo-botanists to belong to the same Lycopodeaceous group. On the other hand, some Continental botanists distinguish them—regarding the former as a genus of Gymnosperms, whilst the latter they agree with British botanists in regarding as Lycopodeaceous. The internal organization of the two genera, however, corresponds so closely as to render the separation into two groups unjustifiable. In a large number of the known forms the internal organization is Lepidodendroid in its young state, and only assumes the conditions which Continental botanists, especially of the French School, regard as characteristic of Sigillaria at a more advanced stage of growth.

The internal organization, then, varies with age. Usually in its youngest state, the central axis is a solid bundle of scalariform vessels. This soon opens out into a more or less sharply defined vascular ring which encloses a cellular

medulla. After a period which seems to have varied in different species, this vascular cylinder is enclosed by a second, which is developed exogenously, and in which the vessels are arranged in radiating vertical laminæ, separated by true medullary rays; it was capable of attaining to a considerable size, through its exogenous mode of growth. This vascular cylinder was enclosed within a very thick bark separable into three layers, the inner and outermost ones being composed of parenchymatous cells whilst the intermediate one consisted of a union of bast-fibres and other oblong cells, forming a modified corky layer. The leaves of Sigillaria and Lepidodendron are undistinguishable from one another. Externally the bark exhibits two very different conditions. In the most extreme Sigillarian type it is fluted longitudinally, the raised ribs having impressed upon them at varying intervals the seal-like scars left by the fallen leaves. In the opposite or Lepidodendron type, these leaf-scars are arranged in diagonal lines and in close contact, the longitudinal flutings being absent; but numerous forms unite these two extremes.

Sigillaria and Lepidodendron alike attained to noble proportions in the Carboniferous period. Sir Charles Lyell mentions an individual Sigillaria 72 feet in length, found at Newcastle;* and a specimen of Lepidodendron from the Jarrow coal-mine was more than 40 feet in length and 13 feet in diameter near the base. Specimens both of Sigillaria and Lepidodendron not unfrequently expand to a diameter of several feet at the base, and from this taper upwards towards the summit. The branching of the fluted Sigillaria is not well understood; that of the Lepidodendroid forms

* "Elements of Geology," 5th edit., p. 376.

is always of the dichotomous type characteristic of the Lycopods.

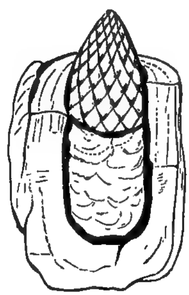
Notwithstanding its size, Lepidodendron has been shown by Brongniart to have its representative in the diminutive club-moss (Lycopodium) of our mountain heaths. This tribe is generally trailing; but in the neighbourhood of the tropics there are a few erect species, one of which, *L. densum* of New Zealand, attains a height of 3 feet.

The nature of the root of Sigillaria was first demonstrated by Mr. E. W. Binney, from observations in the Manchester Coal-field, and it is now known that Lepidodendron possesses the same kind of root. The base of each stem subdivides into four large roots, which again subdivide dichotomously into long radiating branches of the well-known *Stigmaria ficoides*. These branches are covered over by multitudes of small circular indentations, from which emanate carbonized rootlets, penetrating the clay in which the rhizomes are imbedded. They were at first supposed to be a distinct genus of plants; but when Mr. Binney discovered, in the neighbourhood of Manchester, several upright stems of Sigillaria attached by their bases to these spreading rhizomes, it became evident that these portions stood in the relation of stem and root; and fossil-botany now labours under the disadvantage of having two generic names for different parts of the same plant.

The structure of the Stigmaria is peculiar. Surrounding a small cellular pith, which is often destroyed, is a cylinder of barred vessels disposed in radiating wedges separated by medullary rays, and which has been developed exogenously. Some of the medullary rays are enlarged,

and bundles of vessels, derived from the exogenous cylinder are given off through these enlarged rays to supply the rootlets. It appears that the exogenous cylinder is identical with the outer or exogenous cylinder of the stem. The inner or non-exogenous cylinder of the stem, from which the foliar bundles are derived, not being prolonged into the roots, the rootlets consist of a small triangular bundle of barred vessels, surrounded by at least three distinct zones of cellular tissue—extensions of corresponding portions of the bark. The latter differs very little from the bark of Sigillarian and Lepidodendroid stems. These stems are frequently found standing erect upon the coal, traversing the superincumbent strata. Several stems were found standing on the upper surface of a coal-seam at Dixonfold, near Manchester, and some five examples are in the Museum of Owens College, Manchester.

Fig. 2.



Lepidostrobus ornatus in a nodule of ironstone. In the Bristol Museum. (Hooker.)

In the hollow trunks of Lepidodendra small oval or conical bodies (Lepidostrobi) have frequently been found, often in numbers. They are evidently catkins or fruitcones; the outer surface was covered by scales or bracts, within which were contained seeds or spore-cases. See Fig. 2.

When enclosed within the trunk, they are found in an erect position: in other words, with their major axes parallel to that of the tree. Sir. J. W. Hooker, by a series of careful observations, has shown the Lepidostrobi to be the fruit of the tree itself, and accounts for their presence in

the trunks by supposing them to have been washed in by heavy rains and floods when the trunks themselves were standing hollow and decayed.*

LYCOPODITES.—This was a genus of plants allied to *Lepidodendron*, or probably belonging to it, with pinnated branches, and leaves inserted all round the stem in two opposite rows, not leaving clean and well-defined scars.

The genus *Knorria* of Sternberg no longer exists as such, according to the view of Prof. Göppert, who has suggested that it is only a form of *Sagenaria* or *Lepidodendron;* and that the most common species in the Lower Carboniferous rocks, *Knorria imbricata*, belongs to *Sagenaria Weltheimiana.*†

There is now little doubt but that these plants are merely examples of a Sigillarian or Lepidodendroid bark from which the outer layers have become detached.

ULODENDRON.—A plant of which the affinities were long uncertain. It is now clear that it is a Lepidodendroid tree, and that the peculiar, large, round or oval scars which are arranged in two vertical rows on opposite sides of the branches, are areas from which Lepidostrobi have been detached. These cones have recently been found *in situ.*

ASTEROPHYLLITES, SPHENOPHYLLUM, and ANNULARIA.—These are plants with verticils, or small leaves. Some of them are probably Calamitean. Others, especially Asterophyllites and Sphenophyllum, bearing fruit-spikes known as Volkmanniæ, etc., are more probably Lycopodeaceous.

* In Lord Stamford's museum at Enville there is a specimen of Lepidodendron, collected by Mr. H. Beckett, containing three species of bivalve shells.

† "Ueber die fossile Flora der Silurischen der Devonischen und unteren Kohlenformation," 1859.

CONIFERÆ.—It is not without interest that we find coniferous trees to have formed a very important part of the flora of this ancient period of the world's history; so that, as was remarked by Sir C. Lyell, their presence precludes us from characterizing the Carboniferous flora as consisting of imperfectly developed plants, the Coniferæ taking a high, though not the highest, position in the ranks of vegetable organization.*

The prevalent type seems to have been that of the Araucarian, or Norfolk Island Pine; but seed-cones resembling those of the genus *Pinus* have also been found. One specimen from the Newcastle coal-field is figured by Lindley.†

The Coniferæ of the Coal-period differed from those of the present day in the large size of their pith; and the remarkable, and for a long time inexplicable, fossil, found generally in sandstones, known as *Sternbergia*, has been demonstrated by Prof. Williamson to be an inorganic cast of cavities within the pith of these trees.

The little ribbed nodular mass, *Trigonocarpum*, found in great numbers throughout the Coal-measures, formerly considered to be the fruit of a palm, is now known to be the inorganic cast of the interior of the "testa" or integument of a seed which probably belonged to a Coniferous plant. Like those of the Chinese *Salisburia adiantifolia*, this seed had a hard inner shell, invested by a fleshy envelope, the two enclosing the kernel, which has usually disappeared. The

* "Elements," p. 374. The late Mr. Hugh Miller has demonstrated the existence of Coniferæ at a much earlier period—that of the Old Red Sandstone of Scotland. See "Footprints of the Creator," p. 199. Prof. Göppert has recently shown that the Coniferæ make their appearance amongst the upper Devonian Rocks.—"Journ. Geol. Soc.," vol. xvi.

† "Fossil Flora," vol. iii, p. 43.

broad leaves designated *Næggerathia*, formerly regarded as palms, are now known to belong to the genus *Cardaites*, which possessed spikes of unisexual flowers. The plants termed *Antholithes* are the flower spikes, and the seeds known as *Cardiocarpon* are those of some species of this group. These plants display both Coniferous and Cycadean affinities. No traces of palms have been found in the Carboniferous strata, all the plants formerly so regarded being now known to belong either to the Ferns, or to the Gymnospermous group.

The flora of the "Culm," belonging to the Lower Carboniferous series of Devonshire, contains 23 species, of which one plant is marine.

These details may appear to some uninteresting; but they serve to show how necessary is a large acquaintance with the vegetation of the present, before we can rightly understand that of the past. An acquaintance, however varied, with the recent botanical productions of our own country, would tend to throw little light on the nature of that flora which flourished upon the same spot so many ages back. The tropics, and even the diametrically opposite portions of the earth, as New Zealand, Australia, and Norfolk Island, have to be searched in order to furnish analogous productions; and where these are sought for in vain, as in the case of several Carboniferous genera, we find it difficult to picture before our minds those bygone structures of which we possess but the defaced ruins.

We have only here described those forms which were most prolific—many more must have existed of which we have no trace.* We may, however, fully accept the opinion of

* A large number of species of Gymnospermous seeds, many of them of remarkable dimensions, have been found both in England, France, and

Hugh Miller, that this was "a flowerless vegetation." We feel pretty certain on other grounds than the mere absence of their remains, that those orders of plants which refresh our senses with their flowers and fruits (as these terms are commonly understood) existed not in the true Coal-period. There is every reason for believing that the *Rosaceæ*, *Leguminoseæ*, and a few other tribes adapted to charm the eye and minister to the wants of man, only appeared as the harbingers of man himself; therefore, with all the luxuriance of the foliage, and the denseness and stature of the trees which overspread the great lagoons of the Carboniferous period, the general effect must have been sad and sombre in the extreme. But it persisted, through long ages, in unspeakable loneliness and silence, echoing neither voice nor sound, except when some giant of the forest snapped in twain, and fell heavily into the arms of its companions.

America, whilst we have no clue whatever to the important trees to which they belonged.

In the frontispiece, attempted restorations of the plants, together with enlarged sections, are given; 1 and 5 are Lepidodendron trees; 2 and 4, Sigillaria; 3, Asterophyllites; 7, tree-fern; 8, Knorria?; 9, lagoon of the Coal-period.

CHAPTER IV.

THE FORMATION OF COAL.

WHEN Sir William Logan, thirty years ago, was engaged on his great survey of the coal-field of South Wales, he found it to be an invariable rule that every coal-seam reposed on a bed of clay (underclay) penetrated by the rootlets of *Stigmaria ficoides.** This observation has been extended to every coal-field in Britain; and although the character of the underclay varies considerably, sometimes becoming a hard siliceous stone, yet the presence of the carbonized rootlets shows that it has borne the same relation to the coal as have the softer underclays. This observation of Sir W. Logan established the hypothesis that the plants of which coal is formed grew upon the spot where we now find them mineralised, and that the underclays formed the soil from whence they sprung.

Now these underclays are distinctly stratified, showing that they have been deposited under water; and hence it was supposed that in order to become the receptacles for the growth of luxuriant forests, they must have been elevated into dry land; and then, after having been covered by vegetation, were again submerged to be overspread by sands, clays, and other sedimentary materials which combine to form the strata of the coal-measures. This theory required a series of oscillations over a large extent of the

* "Geological Transactions," 2nd series, vol. vi.

earth's surface, which seemed rather improbable, and not in accordance with observations on changes of level which have been made in various parts of the world. That there are slow elevations and subsidences of the surface more or less extensively in operation, is proved by phenomena exhibited on our sea-coasts,* where in some cases old sea-beaches are found at elevations far beyond the reach of the waves, and in others where forests, and even towns, are known to have been engulfed; and the whole of the geological record teaches us that similar vertical movements have been taking place from the earliest periods.

Along the eastern coasts of South America, Mr. Darwin has described the existence of a succession of terraces, rising in tiers from the sea-level up to an elevation of 1,200 feet. He has shown that each of these terraces has in turn been for a long period subjected to the action of the waves, which has swept away a vast quantity of material, and hollowed out caverns in the rock.† Similar old sea-terraces may be seen in Scotland, Norway, and other countries.

Now, as the whole of the land, from the highest terrace down to the level of the ocean, has evidently been under the sea, to have attained its present position it must have been elevated, and each coastline marks a pause in the process of elevation. Here is an example of a constant change of level, with pauses; and it probably furnishes an illustration of Nature's mode of action during the coal-period. The process, however, in this case must be *reversed*, and instead of periodical elevations it is necessary to infer a slow and gradual subsidence of the sea-bed

* For many examples, see Lyell's "Principles of Geology."

† "Voyage of the Beagle," vol. iii, p. 200.

accompanied by pauses marked in many cases by the formation of a seam of coal.*

But another question requires elucidation. The coal-seams are associated with strata deposited under water; and all recent investigation strengthens the probability that this water was generally fresh, sometimes estuarine, or marine. In the northern coal-fields of England, some of the coal-seams are covered by black shales, containing remains of fishes and marine shells, as *Goniatites*, *Aviculo-pecten*, *Orthoceras*; and along the coast of Dunbar, in Scotland, bands of limestone, with marine shells, as *Spirifer*, *Productus*, etc., rest upon coal-beds, and on the upright stems of Sigillaria.† In coal-measures belonging to the higher portion of the Carboniferous series, bivalves which were formerly supposed to belong to the fresh-water genus *Unio*, have since been found in the same stratum with *Modiola* and *Aviculo-pecten*. For this genus we adopt the name *Anthracosia* of Professor King,‡ and believe it to have lived in seas, estuaries, or lakes. Mr. Binney has shown the probability that the little coiled shell (*Micro-conchus carbonarius*) is in reality a coiled *Serpula* or *Spirorbis*, which attached itself to the coal-plants; § and lastly, the minute crustacean abundant in coal-shales, and supposed to have belonged to the fresh-water genus *Cypris*,

* This illustration has previously been employed by the late Mr. E. W. Binney, to whom, more than to any author, we are indebted for our present knowledge of the circumstances under which coal has been formed. It is, however, so apt, that I have no hesitation in producing it here.

† These limestones contain fossil representatives of the Carboniferous limestone of England; and it is well known that a portion of the coal-measures of Scotland are of earlier date than those of England.

‡ "Annals and Magazine of Nat. Hist.," January, 1855.

§ It is scarcely necessary to remark that Serpula is a marine annelid.

is with more probability referred to the marine genus *Cythere.* Whilst admitting, therefore, the prevalence of lacustrine strata in the upper part of the coal-measures, I think we may conclude that the formation has been in part of marine and estuarine origin—a conclusion at which we might arrive on other grounds, when we consider that the formation was at one period continuous over the greater part of Central North America, and would have required for its generation a lake of a size at least six times the area of all the great lakes of that continent united.

There are two conclusions which strike us most forcibly when reflecting on the formation of our coal-fields: the enormous subsidence of the original surface, and the lapse of time it must have required to produce a series of strata, with their coal-seams, in all, several thousand feet in thickness.

Recollecting that every bed of true coal *represents* a land-surface, or at least a sea-level, when we find, as in the case of the coal-field of South Wales or of Nova Scotia, strata with coal-beds through a thickness of 10,000 or 12,000 feet, it is evident that this is a measure of the actual sinking of the surface for this one geological period. To take an example:—the height of Mont Blanc is about 15,000 feet; now the vertical displacement which the South Wales coal-field underwent was nearly sufficient to have brought the summit of the Alps to the sea-level.

Of the lapse of time during the formation of our coal-fields we can have but a faint conception; it is only to be truly measured by Him with whom "a thousand years are as one day." But the magnitude of the time is only surpassed by the boundlessness of the providential care which laid up

these terrestrial treasures in store for His children, whom He was afterwards to call into being. Let me therefore dismiss this subject with one illustration. Mr. Maclaren, by a happy train of reasoning, for which I must refer the reader to his "Geology of Fife,"* arrives at the conclusion that it would require a thousand years to form a bed of coal one yard thick. Now, in the South Wales coal-field there is a combined thickness of coal amounting to 120 feet, or 40 yards, which, according to this hypothesis would have required a period of 40,000 years for its formation. If we assume that the 12,000 feet of sedimentary material was deposited at the average rate of 2 feet in a century, corresponding to the rate of subsidence, it would have required $\frac{12000 \times 100}{2} + 40{,}000 = 640{,}000$ years to produce this coal-field.†

I have spoken of the difficulty of conceiving frequent *elevations* of the sea-bed during the long period of subsidence in order that a land surface might be laid dry for the growth of vegetation. A much more probable supposition is, that the coal-plants were fitted to grow with roots and stems partially submerged. Analogy would lead us to this conclusion in the case of *Sigillaria*, *Calamites*, etc., and among the dense forests of larger trees there may have been an undergrowth of reeds and grasses.

* P. 116.

† In this estimate I have adopted a medium between two extreme estimates given by Lyell, "Elements," pp. 386, 387. For a good *résumé* of this subject, see Jukes' "Manual of Geology," p. 95, *et seq.*

The late Prof. Phillips attempted a calculation of the time required for the production of this coal-field founded on the supposition of the sedimentary materials having been formed at the mouth of a large river, such as the Ganges, and the carbonaceous portions having been stored up at the rate of 1 inch in 127·2 years; the result arrived at being about half a million of years. —"Life on the Earth," p. 134.

The great swamps at the estuary of the Mississippi, and those along the coasts of Louisiana, Nova Scotia, and the tropical lagoons of the African coast, furnish us with the nearest representations of the nature of those forests that have produced our coal-beds; but none of them are strictly analogous. The physical conditions of the coal-period stand alone; and we cannot but conclude that they were ordained beforehand for a great and evident purpose.

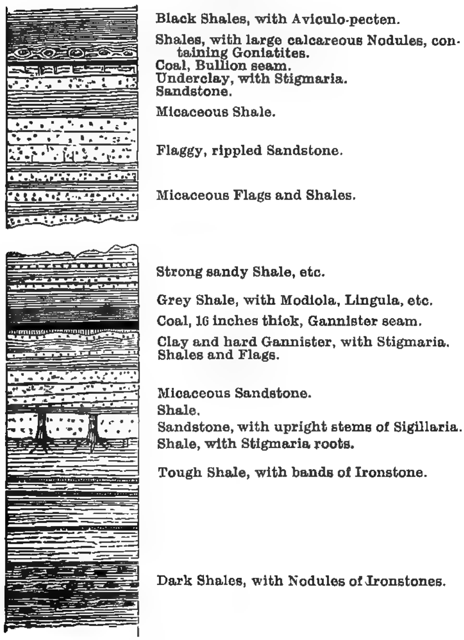
The strata which are associated with the coal consist of sandstones, which were once sand; shales, and fire-clays, which were once fine mud. Some of the shales are so highly carbonaceous as to be nearly black, and form impure coal called "bass." Bands of limestone occur in the higher beds of the coal-measures in England, and throughout the greater portion of the formation in Scotland.

The sandstones are frequently rippled, and obliquely laminated, showing the prevalence of currents; they also contain fragments of drifted plants. The shales are generally laminated, showing a slow and tranquil deposition. The general succession of strata which accompany coal is shown in the annexed section, taken from the neighbourhood of Wigan, and belonging to the lower coal-measures or Gannister series.

Of coal, as a mineral, I must here say a few words. All the coal of the older formations, except the better sorts of "cannel," presents in a cross-section a truly laminated aspect, and consists of layers of glossy, bituminous coal, alternating with thinner bands of anthracite. The former class presents no trace of organic structure; while in the latter, under the microscope, the various tissues of Araucaria, Sigillaria, and other plants, as well as their fructification, may be detected.

There can be no doubt but that this laminated structure is the result of accumulation under water; and Bischof* adopts this view upon other considerations. He says, The conversion of vegetable substances into coal has

Fig. 3.
Succession of Strata in Lower Coal-measures, near Wigan, Lancashire.



certainly been effected by the agency of water." The same great authority believes that coal has been formed, not from the dwarfish mosses, sedges, and other plants which

* "Chemical Geology," vol. i, Messrs. Paul and Drummond's Trans.

now contribute to the growth of our peat-bogs, but from the stems and trunks of the forest trees of the Carboniferous period, such as Sigillariæ, Lepidodendra, and Coniferæ.

The earthy portion of coal, which after combustion forms ash, is disseminated in minute particles throughout the entire mass, which could only have occurred by infiltration ; but before woody fibre is in a state to admit of the infiltration of sediment mechanically suspended in water, it must have undergone partial destruction. Hence we may conclude that, as the forest trees successively fell through age or accident, they were immersed in water—which must have been shallow, and which held in suspension particles of clay or sand. Mr. H. Taylor gives the following analysis of the ash of a good coal-seam from Newcastle :—

Silica	59·56
Alumina	12·19
Peroxide of iron	15·96
Lime	9·99
Magnesia	1·13
Potash	1·17
	100·00

Bischof has shown that this analysis does not much differ from that of many of the shales with which the coal is associated.

The conversion of wood into coal may take place in four different ways, namely :—

1. By the separation of carbonic acid gas and carburetted hydrogen.
2. ,, ,, carbonic acid gas and water.
3. ,, ,, carburetted hydrogen and water.
4. ,, ,, carbonic acid, carburetted hydrogen, and water.

And from the mean of 67 analyses given by Bischof, it appears that by three of these processes the wood

	Lost	and	Yielded.
In 1—	78·0 per cent.		22·0 per cent. of coal.
In 2—	57·3 ,,		41·7 ,, ,,
In 3—	45·5 ,,		54·5 ,, ,,

The copious discharge of carbonic acid and carburetted hydrogen given off by wood in its conversion into coal, appears to have taken place for the most part during the progress of decomposition in the coal-period; for it has been found by a comparison of the analyses of true coal with the lignite of the Tertiary strata, that the difference in the percentage of oxygen and hydrogen in these two classes of minerals is not very great. In lignite the oxygen is only 1·54 per cent., and the hydrogen only 0·38 per cent. more than in true coal. It would therefore appear that, in the long lapse of time between the Carboniferous and Tertiary periods, the coal experienced an extremely slight loss of substance. In the coal-fields these gases are constantly escaping in jets from the shallower seams; but in the deeper parts they are pent up at an enormous pressure, and by their elastic force materially assist the miner in his excavations.

Analysis of 8 Specimens of Coal from Newcastle, Glasgow, Lancashire, Edinburgh, and Durham (Bischof).

Carbon.		Hydrogen.		Oxygen and Nitrogen.		Earths.	
Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
89·2	79·1	7·2	5·3	14·5	5·5	2·9	0·5

*Analysis of Anthracite from Pembrokeshire, by Schafhäult.**

Carbon.	Hydrogen.	Oxygen and Nitrogen.		Earths.
94·10	2·39	1·34	0·87	1·30

* Dana's "Mineralogy."

*Analysis of Brown Coal (Lignite), from Elbogen.**

Carbon.	Hydrogen.	Oxygen and Nitrogen.	Earths.
73·79	7·46	13·79	4·96

Of Britain it may be emphatically said, "whose stones are iron, and out of whose hills thou mayest dig brass." Clay ironstone abounds in the shales of every coal-field, either in the form of nodules or in thin courses. She has also erected more altars to Vulcan than any other country, and the products of her Carboniferous rocks—the coal, ironstone, and limestone—have enabled her to take the foremost place in the industrial arts.

The coal formation is very frequently traversed by vertical fractures or *faults*, which, within a few yards or feet, completely change the series of strata and the mineral character of the district. These faults are actually vertical dislocations of the rocks, the beds having been upheaved or depressed, as the case may be, tens, hundreds, or even thousands of feet along the line of fracture. Many examples will be produced when I come to treat of the coal-fields; but I may mention that some of the faults which traverse the coal districts of Lancashire and Staffordshire dislocate the strata to the amount of 600, 700, or even 1,000 yards!

The coal-measures of England rest upon a series of hard and coarse sandstones and shales—called "Millstone Grit"; this again on a thick series of shales and grits, "the Yoredale rocks," which pass downwards by the intermixture of courses of limestone into the great calcareous deposit, the Carboniferous Limestone. This last formation attains in Derbyshire a thickness of 5,000 feet, and is surcharged with marine fossils throughout; indeed, it is

* Phillips' "Mineralogy."

almost wholly composed of the shells of mollusca, the calcareous habitations of corals, or the broken skeletons of Crinoidea or "stone lilies." These last must have covered the bottom of the ocean in countless myriads, forming miniature forests, which rose generation after generation upon the accumulating layers of their perished ancestors, until their remains were sufficient to form thick beds of limestone, extending for many miles in every direction. In some parts of Derbyshire and Yorkshire the limestone appears to be composed of little else than the disjointed skeletons of Crinoidea; the minute shells of Foraminifera are also generally abundant.

The coal-measures are overlaid by the Permian formation, consisting of three members: the lower composed of red and purple sandstones, marls, calcareous conglomerate, and breccia; the middle, of magnesian limestone of the north-eastern counties; the upper, of gypseous marls and sandstones. This formation is sometimes unconformable to the coal-measures, and always to the Trias which succeeds it.

Next in succession is the Trias, or New Red Sandstone, which, in the absence of the Permian strata, sometimes rests directly upon the Carboniferous rocks. It consists of two members, the Bunter and Keuper; the middle member, the Muschelkalk, being absent in Britain.

The Bunter Sandstone consists of three members: the lower, soft red and variegated sandstone; the middle, quartzose conglomerates and red pebbly sandstone; the upper, soft-streaked and variegated sandstone. Upon this the Keuper series rests unconformably, the upper surface of the Bunter Sandstone being frequently eroded and waterworn. The Lower Keuper Sandstone is introduced

by calcareous breccia, and passes upwards into the laminated Red Marl or Keuper formation.

We are now in a position to comprehend in some measure the formation of a coal-seam in olden time.

Let us suppose that a certain bed of coal has been completed by the growth of luxuriant plants over a low-lying tract subject to inundations. Rising ground of granitic, schistose, or Lower Palæozoic rocks in the distance defines the margin of the basin, and the boundaries of continental land from which the sedimentary materials of the coal strata are derived. That growth of vegetation marks a period of rest; but now a slow subsidence of the whole tract commences. The brackish waters of the estuary, or the salt waters from the ocean, invade the jungle, carrying dark mud in suspension, with floating stems of trees and fronds of ferns. Presently the mud subsides, and covers in one uniform sheet the accumulated vegetation of centuries. The process of subsidence goes on, while the river currents pour into the estuary fine sand and mud, in which branches and stems of trees from the uplands are often included. This process continues until the sinking of the ocean bed either altogether ceases, or is counterbalanced by the rapidity with which the sediment is deposited. The basin becomes gradually shallower, and the plants begin to reappear, commencing perhaps at the margin, and creeping outwards until the whole basin is again overspread by a forest of huge cryptogamic trees, aborescent ferns, and tall conifers. These, generation after generation, flourish and die; their leaves, branches, and trunks falling around, and gradually accumulating till the pulpy mass attains a thickness of 20, 50, or 100 feet. The process concluded, the basin again commences to

subside, the waters return and bury the mass for, perhaps, hundreds of years; stratum after stratum accumulates, till the vegetable pulp is subjected to the pressure of, it may be, thousands of feet of solid matter. Meanwhile, chemical, as well as mechanical, changes ensue, and in process of time what was once a forest is changed into a bed of coal. By a repetition of this process, with local variations, we may conceive the formation of any number of coal-seams, amounting, in some districts, to 50 or 60, and embraced within a vertical thickness of several thousand feet of shales, clays, and sandstones. Ages roll on, the strata are moved from their foundations; upheaved into ridges and plateaux, the rains, rivers and currents sweep away a portion of the covering, and the mineral treasures are brought within the reach of mining industry.

CLASSIFICATION OF CARBONIFEROUS AND NEIGHBOURING FORMATIONS.

The following view of the formations which lie immediately above and below the coal-measures may prove useful for reference. It is applicable, I believe, to the whole of Britain. The tripartite division which I have adopted for the coal-measures of England and Wales is not, as yet, generally recognised, but every day's experience tends to make the necessity for such a division more than probable.

Tabular View of the Triassic, Permian, and Carboniferous Series in England and Wales.

New Red Sandstone or Trias.	Keuper ...	Red marl. Lower Keuper sandstone, with calcareous breccia in lower part (Somersetshire, etc.).
	Bunter ...	Upper mottled sandstone. Conglomerate beds. Lower mottled sandstone.
Permian Rocks ...	... ...	Upper red sandstone of St. Bees', etc. Upper and lower magnesium limestones and marls of the northern counties. Lower red sandstone of Lancashire, Cumberland, Yorkshire, etc. (on the same horizon with). Red sandstones, marls, conglomerates, and breccias of the central counties and Salop. (Rothetodte liegende.)
Carboniferous Rocks.	Upper Carboniferous	Upper Coal-measures, with "Spirorbis limestone" and thin coal-seams. Middle Coal-measures, with thick coal-seams.
	Middle Carboniferous	Lower Coal-measures or Gannister series, with thin coal-seams and marine fossils. Millstone grit, with thin coal-seams. Upper limestone shale or "Yoredale rocks," with marine fossils.
	Lower Carboniferous	Carboniferous limestone with marine fossils. Lower limestone shale, or Calciferous sandstone series; fossils marine.*

* In Ireland the Coomhola grits and Carboniferous slate belong to this division, and in Devonshire the "Barnstaple," "Pilton," and "Marwood beds." ("Quart. Journ. Geol. Soc.," May, 1880, p. 262.)

Old Red Sandstone	Kiltorcan beds with *Anodonta Jukesii* in Ireland (Lacustrine). Old red sandstone and conglomerate. "Pickwell Down sandstone" of Devonshire (Lacustrine).
Devonian Rocks...	Marine beds of Ilfracombe and Lynton (absent in Ireland and Scotland). (Represented by the "Cornstone series" of Herefordshire.) Upper and Lower Silurian rocks.

In examining the Fauna of the Carboniferous series from its base upwards over the British and adjoining Continental areas, we shall find that we ascend through a vast series of essentially marine strata, with oceanic beds like those of the Carboniferous Limestone, until we reach the top of the Gannister beds, or Lower Coal-measures of England, where a change occurs in the character of the fossil forms, and the marine organisms give place to those of fresh water or estuarine characters. Upon this change in the character of the Fauna the above classification of Lower, Middle, and Upper Carboniferous beds is based—the foundation of the whole series being the lacustrine beds of the Old Red Sandstone of England, Ireland, and Scotland, with its peculiar Fauna and Flora. Thus the Lower and Middle Carboniferous beds form a marine series interposed between the lacustrine beds of the Old Red Sandstone on the one hand, and those of the Upper Carboniferous series on the other. The following table (p. 46) will show the representative beds according to this classification over the area above stated.*

* This classification is in conformity with the views I have put forth in my paper "On the Upper Limit of the Essentially Marine Beds of the Carboniferous Group of the British Isles," etc. ("Quart. Journ. Geol. Soc.," November, 1877.)

Having thus given a brief sketch of the nature of coal, its origin, and the strata with which it is associated, we are now prepared to pass on to the consideration of the coal-fields themselves.

TABLE OF REPRESENTATIVE

	Stages.	England and Wales.		Ire-
		North.	South.	North.
Upper.	G.	Upper Coal-measures of Manchester, etc., Staffordshire, Denbighshire.	Generally absent (through denudation).	Absent (through denudation).
	F.	Middle Coal-measures with thick coal-seams, etc., Lancashire, Yorkshire, Derbyshire, etc.	Middle Coal-measures, of South Wales and Somersetshire, etc.	Coal-Island Coal-field, co. Tyrone.
Middle.	E.	"Gannister Beds," or Lower Coal-measures.	Lower Coal-measures, with ironstones and thin coals.	Lower Coal-measures of Drumglas (Tyrone), coal-fields, of Lough Allen (co. Leitrim).
	D.	Millstone Grit series, Lancashire, Yorkshire, Derbyshire, etc.	Millstone Grit, or "Farewell Rock."	Millstone Grit of Fermanagh, Sligo, etc. (Cuilcagh).
	C.	Yoredale series, or Upper Limestone shale. "Upper Bernician beds" (Lebour).	Upper Limestone shale (thin).	Ironstone shales of Lough Allen, also of Drumglas (co. Tyrone).
Lower.	B.	"Mountain Limestone" of Derbyshire, "Scaur or Scar" Limestone (Sedgwick).	Carboniferous Limestone of Cheddar, the Wye, Avon, and S. Wales, etc.	Carboniferous Limestone in three divisions. Ballycastle Coal-field, co. Antrim (in part).
	A.	"Tuedian Group" (Tate), often absent in N. Lancashire, etc.	Lower limestone shale (thin).	Calciferous Sandstone series or Lower Carboniferous Grits.

CARBONIFEROUS FORMATIONS.

LAND.	SCOTLAND.	CONTINENTAL.	Condition of Deposition.
South.	Central.	Belgium and Germany.	
Absent (through denudation).	Upper red sandstones of Bothwell, etc., Ayrshire, beds with Spirorbis Limestone.	Possibly present in the Belgian and Saarbrück Coal-fields.	Essentially estuarine and lacustrine, with intrusions of the sea at long intervals.
Leinster Coal-field, from "the Jarrow Coal" upwards.	"Flat-coal" series or "Upper-coal" series of Scotland with thick coals.	Main Coal-measures of Belgium, Saarbrück, Westphalia, Saxony, and Silesia, etc.	
Lower Coal-measures of Leinster, Modubeagh, Tollerton, Skehana, and Slieveardagh, etc.	Beds on the horizon of "the Slatyband" ironstone? (marine fossils).	Schistes de Lens, Auchy-au-Bois, Chokier. Bottom shales of the Coal-measures of Silesia, etc.	Essentially marine, rarely estuarine. (Sea shallower than in Stage B.)
Flagstone series of Carlow, Kilkenny, Clare, etc.	"Moorstone rock" and Roslin sandstone.	Generally absent in Belgium, Flötzleerer Sandstein of Germany.	
"Shale series" of Carlow, Kilkenny, Clare, etc.	"Upper Limestone series" resting on "Lower Coal and ironstone series"?	Calcaire de Visé. Bruchberg crinoidal sandstone (Harz)?	
Carboniferous Limestone, in three divisions.	"Lower Limestone series" of Gilmerton, Roman camp, etc.	Carboniferous Limestone of Belgium (Calc. de Dinant, Calc. de Tournai), France, Germany, Russia, etc.	Essentially marine, and deep-sea beds (except occasionally in Scotland, where lacustrine or estuarine beds occur).
Lower Carboniferous slate (in part) with Coomhola grits.	Calciferous Sandstone series in two groups.	"Schistes de Tournai," and "Kiesel-Schiefer," etc. "Jüngere Grauwacke" of the Vosges and of the Schwarzwald.	

PART II

CHAPTER I.

THE GREAT COAL BASIN OF SOUTH WALES.

THE coal-basin of south Wales is, with the exception of that of the Clyde Basin, the largest in Britain, and contains almost as great a vertical thickness of strata as any coal-field in the world, amounting to upwards of 10,000 feet.

It is separated by Caermarthen Bay into two unequal portions. That to the east of the bay stretches to Pontypool, in Monmouthshire, a distance of 56 miles, and is the larger portion. The smaller extends to St. Bride's Bay, a distance of 17 miles, and is washed by the waves of the Atlantic. The greatest transverse diameter is 16 miles, in the meridian of Neath, in Glamorganshire.

The general form of the coal-field is that of an oval basin or trough, lying nearly east and west. It is deeply indented by the bays of Swansea and Caermarthen, which overspread the upturned edges of the strata as they cross from shore to shore. The beds also rise and crop out towards the north, beyond which the Millstone Grit and Carboniferous Limestone mark the limits of the coal-producing area, often terminating in a series of fine escarpments with northerly aspects. The superficial area of the basin may be stated at 906 square miles.

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The coal-field east of Caermarthen Bay is traversed throughout nearly the whole of its length by a remarkable anticlinal axis, which has been traced from the north of Risca, by Pontypridd and Ton-yr-efail, across the Lesser Ogwr, by Nant-Tyrus, the Masteg ironworks, and Aberavon beneath Swansea Bay.* The basin is thus divided into a northern and southern trough, lying on either side of the great anticlinal axis, of which the former occupies twice the area of the latter. The effect of this axis is to bring the lower coals within reach of mining operations along a considerable tract of country.†

It is also worthy of note that this line of elevation is so placed as to be nearer to the southern side of the basin where the dip inwards along the margin is steepest; so that, were it not for the existence of this flexure, the lowest seams (which are of great value) would have been placed at depths far beyond the reach of mining operations, within a comparatively short distance of their outcrop. The result of this arrangement of the strata, however, is most favourable for their recovery by mining; as, in consequence of the anticlinal, these seams of coal are brought again either near to the surface, or within depths where they may ultimately be rendered available. The effect of this anticlinal is shown in the accompanying section (Fig. 4, p. 50) across the coal-field in a north and south direction. Another anticlinal axis ranging in a parallel direction enters Caermarthen Bay south of Kidwelly.

* Mr. H. Hussey Vivian, M.P., and Mr. G. T. Clark, "Rep. Coal-Commissions," vol. i, pp. 1 and 9.

† This flexure is very well represented on the horizontal sections of the coal-field, published by the Geological Survey, and drawn by Mr. Williams and Sir H. de la Beche.

Fig. 4.—SECTION ACROSS THE COAL-FIELD OF SOUTH WALES.
Length about 20 miles.

A_1. Coal-measures, with coal. A_2. Pennant Sandstones. B. Millstone Grit. C. Carboniferous Limestone. D. Old Red Sandstone.

Scenery. — Along its northern border, the coal-field partakes of a mountainous character, rising into lofty tabulated or slightly sloping hills, terminating abruptly towards the northern outcrop of the beds, and indented by deep valleys, which often coincide with lines of dislocation. These valleys, extending inwards in a southerly direction, afford facilities for working the seams of coal by means of adits and galleries stretching far beneath the hills. Beyond the limits of the coal-measures, the hard siliceous sandstones and conglomerates of the Millstone Grit form an encircling zone; and from beneath these the more splintery beds of the Carboniferous Limestone rise to the surface, and present towards the north a range of scarped terraces, often broken through by valleys and gorges which have been determined by faults, but on the whole preserving a general direction parallel to the *strike* or direction of the beds, and attaining an elevation of 2,000 feet. Along the southern boundary of the coal-field, these Lower Carboniferous formations produce a rich and varied scenery, but not of so bold and elevated a character as along the northern margin.

From Swansea Bay eastwards, the Pennant Sandstone rises into high terraced hills, with abrupt slopes facing the shore of the Bristol Channel.

As Mr. Clark has justly observed, it is mainly owing to the intersection of the coal-field by the great valleys of the Nedd, Afon, Ogwr, Taff, Rhymney, and Ebbw, and their subordinates, the Ely, Rhondda, Cynon, Sirhowy, and the Afon Llwyd, that there are more than ordinary facilities for working coal economically, as much of it is recoverable simply by driving adits from the outcrop. On this account it is, that up to a recent period, the coal-pits were generally shallow as compared with those of the north of England; but, during the past few years, mining by adits and shallow pits has given place to collieries with pits of considerable depth, and capable of a large turnout of coal.

Surveys.—As far back as the close of the 16th century, George Owen, a native of Pembrokeshire, drew up a very clear description of the physical features of the South Wales coal-field, tracing the trend of the coal-seams and beds of mountain limestone, and pointing out the relationship of these formations to their representatives in Gloucester and Somerset.* After the completion of the Ordnance Surveys, the geological delineation commenced by Sir E. Logan was subsequently completed by Sir H. T. de la Beche and Mr. Williams, during 1837 and the following years. They have left us a series of beautifully-executed maps and sections, presenting the details as far as they were discoverable at a time when the coal-field had been very partially explored by mining operations. Of these documents it was stated by a com-

* This work was left behind in MS., but was afterwards published in the "Cambrian Register," and reflects the highest credit on the author.

petent judge, that they at once placed the proprietors of coal property in the possession of information which it would have taken 30 years to acquire by the advance of mining enterprise.

More recently a fresh survey was undertaken for the Royal Coal-Commission by Messrs. H. Hussey Vivian and G. T. Clark, with the assistance of Mr. Evan Daniel, of a very elaborate nature, in which the areas of the different groups of coal-seams, according to depth, are represented on 18 plans; they furnish us with a complete anatomy of the structure of the district. This work, accompanied as it is by elaborate tables containing the area, thickness, and quantities of coal in each seam, has been one of more than ordinary labour. The survey on the 6-inch scale, now in progress by the Government, will leave nothing to be desired for fulness and accuracy of detail.

General Succession of Strata and their thicknesses in Monmouthshire.

Coal-measures.—Shales, with ironstones; sandstones, including the "Gower series," and *coal-beds*, of which there are about 25 more than 2 feet thick; total thickness, 11,650 feet.

Millstone Grit (Farewell Rock).—Beds of hard sandstone and conglomerate, with partings of shale (Merthyr Tydvil); thickness, 330 feet.

Carboniferous Limestone.—Upper beds consisting of alternating dark shales with bands of limestone, passing downwards into massive beds of the latter; thickness, 1,000 feet.

Old Red Sandstone.—Sandstone and conglomerate; 600 feet.

Devonian Beds (*Estuarine*).—Red and brown sandstone, marls, and calcareous cornstones; thickness, 6,000 feet, or less.

Westward of Swansea Bay the Millstone Grit disappears, and the Lower Coal-measures rest directly upon the

Carboniferous Limestone. At Haverfordwest this latter also vanishes, and inland from St. Bride's Bay the coal-measures repose on Lower Silurian Rocks. These changes indicate the proximity of land towards the west during the Lower Carboniferous period.

Anthracite and Bituminous Coal-Districts.—It is well known that the coal-seams undergo a remarkable change in their extention from the east towards the west. While in the former direction they are bituminous, or gaseous, upon reaching the centre of the area, the same coal-seams become semi-bituminous, or "steam coals," and farther west, gradually pass into anthracite. Sir H. de la Beche states that this change takes place along a plane, dipping gently towards the S.S.E.; so that in the same spot, while the coals at the base of a hill may be anthracitic, those which outcrop along the heights above may be bituminous, Nor is this alteration in the character of the coals accompanied by outbursts of igneous rock, or by violent crumplings and contortions of the beds, as is the case in the Alleghany Mountains of America, where a similar change has been produced; on the contrary, the strata are usually but slightly thrown out of the horizontal position, except along the tract lying along the Gwen Draethfawr to the north of Mynydd Sulen, where the beds are considerably bent and folded. Other causes must therefore be sought for.

To the agency of a high internal temperature we must doubtless refer this change in the constitution of the coal-seams. Wherever experiments or observations have been made, it has been found that the temperature increases with the depth; and in the case of the South Wales basin, some of the seams have originally been covered by 10,000 or 12,000 feet of strata, and their temperature in consequence

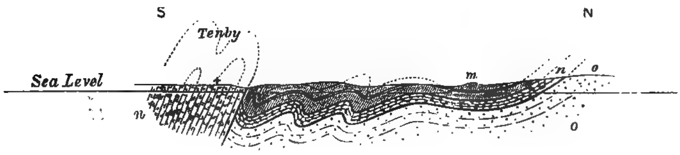
raised above that of boiling water. Under such circumstances, the gases, we may suppose, would be slowly liberated from the coal-seams along faults and fissures, and anthracite would be the result. But how are we to account for this metamorphic action taking place over one portion of the coal-field, and not over the other? This is, indeed, a problem difficult to solve, since the conditions in either portion do not seem to have been materially different. We may offer conjectural solutions of it, such as the greater increase of temperature over the western, or anthracitic, region, as compared with that over the eastern. This is the view advocated by Mr. E. T. Hardman, who supposes that the western extremity of the coal-tract has been subjected to a deep-seated and high temperature, due to the intrusion of masses of molten rock, and he points to the granitic and trappean rocks in the neighbourhood of Rosemarket, and the northern arm of Milford Haven, which are of later date (according to the views of Sir H. T. De la Beche) than the Carboniferous rocks, as evidences of such igneous action.*

Pembrokeshire.—The western limit of the coal-field, containing only anthracite coal, has been subjected to considerable terrestrial disturbance, being much flexured and faulted. The general structure, along a line drawn from north to south, is represented in the following section, Fig. 5, from a drawing by Prof. Sir J. Prestwich.†

* "On the Origin of Anthracite;" Journ. Roy. Geol. Soc. of Ireland, vol. iv, p. 203.

† Prestwich has instituted a just comparison between the flexures of the Pembrokeshire coal-field, and those of the Somersetshire coal-field along the base of the Mendip Hills, with the flexures of the Franco-Belgian coal-trough. Similar views were previously enunciated by Mr. R. Godwin-Austen.

Fig. 5.—SECTION ACROSS THE PEMBROKESHIRE COAL-FIELD.
Eight Miles.



m. Coal-measures.
n. Carboniferous Limestone.
o. Old Red Sandstone.

General Succession of the Coal-series in Glamorganshire and Monmouthshire.

Upper Pellengare Series, more than 3,400 *feet.*	1. Sandstones and shales down to the Mynydd Isslwyn coal. 2. Strata, with 26 coal-seams down to the Hughes vein : nine seams over 2 feet in thickness.
Pennant Grit Series, 3,246 *feet* (Swansea).	Hard and thick-bedding sandstones, etc., with 15 coal-seams; five over 2 feet in thickness.
Lower Coal-measures, 450 *to* 850 *feet.*	Principally shales, rich in ironstone and coal-seams, of which there are 34 in all, and eight above 2 feet in thickness.
Millstone Grit ...	Represented in the south by the Gower series.

It will be observed from the above general summary, taken from the Memoir of Sir H. T. De la Beche,* that the richest coal-bearing strata lie at the top and bottom of the formation; the central portion, formed of the Pennant Sandstone, being comparatively impoverished.

Lower Coal-measures.—These beds along the southern borders of the field form a well-marked zone, very rich in coal and ironstone, and distinguished by a remarkable group of fossil shells of marine genera ; some of the species

* "Memoirs of Geological Survey," vol. i.

—as is also the case in the lower measures of the north of England—having survived from the period of the Carboniferous limestone. It is a very remarkable fact that these lower measures appear to form the upper limit of an essentially marine fauna, the shells which occur in the higher beds being usually confined to the genus *Anthracosia* and its allies; and whatever may have been the conditions under which this genus of molluscs lived—whether (as once supposed) in fresh water, or in brackish,—the extent of its range, as compared with the Goniatites, Nautili, Pectens, Spirifers, and other shells of the Lower Coal-measures, seems to point to some marked physical difference between the original conditions of deposition of the middle, as compared with the lower portions of the coal formation.

The fossils of the Lower Coal-measures are found principally in the ironstones. The coal-seams occur in greatest number and thickness along the southern outcrop, where the series attains a thickness of nearly 1,000 feet.

Pennant Grit Series.—The Lower measures are surmounted by a great series of sandstones, introduced by the "Cockshoot rock," and included under the general term "Pennant Grit," the same by which this series is designated in Somersetshire. These sandstones form a fine range of escarpments, often reaching 1,000 feet in elevation; and within these escarpments is enclosed the great central table-land of Glamorganshire, composed of the higher strata of the Coal-formation. Along the deep valleys by which this region is intersected, the coal-beds often crop out, and have been worked by tunnelling into the heart of the hills. The whole series of strata, from the uppermost Pellengare beds down to the Millstone Grit, is from 10,000 to 12,000 feet in thickness, containing about

80 seams of coal, of which 25 are from 2 feet upwards, with an aggregate thickness of 84 feet of workable coal.* This great series is only surpassed in vertical development by that of Nova Scotia and Saarbrück in Rhenish Prussia; and it should be recollected that, as there is no certainty that the original uppermost beds of the Coal-measures are amongst those now existing on the central table-land, we are in ignorance of the actual thickness of the formation as originally deposited.

The following is a complete series of the coal-seams, with their corresponding names or designations, along the north and south outcrop, and their ascertained thicknesses, either individually or in groups. The series commences with the lowest bed, which has, in consequence, the largest area, and terminates with the uppermost.† (See p. 58.)

Relative Areas of Varieties of Coal in the Western Part of the Coalfield.—On this subject Mr. John Roberts gave valuable information before the Commissioners‡ for the district extending from Carmarthen Bay eastward to a line drawn in a north-easterly direction from Port Talbot into Brecknockshire. In the northern area of 133 square miles the coal is anthracitic; in the next division to the south, of 77 square miles, the upper seams consist of steam coal, the lower of anthracite; in the next division, which passes through Llanelly and Neath, with an area of 61 square miles, is the chief steam coal band of country; and lastly, to the south of this, in the band of country

* The combined thickness of all the coal-seams, small and great, is stated by Prof. Phillips to reach 120 feet.

† This table is copied from Mr. Vivian's "Report," drawn up for the Coal Commission of 1871, vol. i.

‡ Roy. Com. on Coal Supplies, 2nd Rep., 1904.

Coal Seams of the South Wales Basin.

Name in ascending Order of each Seam or Vein of Coal, One Foot and upwards in Thickness, contained in each Plan.*			Distinguishing the respective Crops of the Veins, with their various Thicknesses.	
North Crop.	South Crop, North of Anticlinal.	South of Anticlinal.	Crops.	ft. in.
Crowsfoot vein. (Bottom seam.)	Crowsfoot vein. (Bottom seam.)	Crowsfoot vein.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. .. Doubtful, and under the sea Plan No. 1	1 6 2 0 2 0 2 0 —
Pimp Quart vein. Fach vein Rhasfach vein.	Rider. Four and Five Feet vein. Coal.	Five Quarters vein. Cribbwr Fawr vein. Cribbwr Fach vein.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. . Doubtful, and under the sea Plan No. 2 ..	6 6 10 2 13 7 10 2 —
Hwch vein. Stenllyd vein. Grasuchaf vein. Grasissaf vein. Bresllwyd vein. Gwendraeth vein. Triquart vein.	Four Feet vein. Balance Pit vein. Tusker vein. Clay vein. Big vein (in Wem level.)	Three Feet vein. Six Feet vein. Rider. Smoke vein. Rider. " Nine Feet vein. Danllyd vein.	North crop .. .. .. South crop (north of anticlinal) .. .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 3 ..	20 5 12 6 30 7 12 6 —
White vein. Black vein. Little vein. Harnlo vein.	Coal and Mine vein. Five Feet vein.	Three Feet rider. South Fawr vein. Clay vein. Four Feet vein. Rider.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 4 ..	14 0 8 2 21 11 8 2 —
Black Mine vein. Soap vein. Coal. Penstwryn vein.	Finery vein. Sulphury vein. Four Feet vein. Truro vein. Rider. Clay vein.	North Fawr vein. Three Feet vein.	North crop .. .. .. South crop (north of anticlinal) .. .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 5	8 6 22 11 11 4 22 11 —

* The plans referred to are those in the Report.

Coal Seams of the South Wales Basin—continued.

Name in ascending Order of each Seam or Vein of Coal, One Foot and upwards in Thickness, contained in each Plan.			Distinguishing the respective Crops of the Veins, with their various Thicknesses.		
North Crop.	South Crop, North of Anticlinal.	South of Anticlinal.	Crops.	ft.	in.
Coal. " " " Fforch-y-Garen vein.	Coal. Cockshut rider. Silver vein. Balling vein.	Bwdwr Fach vein. Bwdwr Fawr vein. Sooty vein. Coal.	North crop .. .. .. South crop (north of anticlinal) .. .. .. South of anticlinal .. Doubtful and under the sea Plan No. 6	9 5 21 5 —	9 3 5 3
Nil.	Black vein. Coal. " " Golden vein. Cockshut vein. Coal.	Bridge vein. Lantern vein.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. .. Doubtful, and under the sea Plan No. 7	— 14 8 14 —	 10 6 10
Nil.	Cwmbyr vein. Cwmmawr vein.	Small vein.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 8	— 3 1 3 —	 11 6 11
Coal. " " Llyngola vein.	Tormynydd vein. Jonah vein. White vein. Rider. Clay vein.	Double vein.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 9	9 12 3 12 —	2 3 0 3
Coal. " " Goch vein. " " " "	Field vein. Werndfi vein. " rider. Wernpistill rider. " vein. Benson's vein.	Matthouse vein. Rock Fach vein. Rock Fawr vein.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 10	14 13 9 13 —	10 7 4 7

Coal Seams of the South Wales Basin—continued.

Name in ascending Order of each Seam or Vein of Coal, One Foot and upwards in Thickness, contained in each Plan.			Distinguishing the respective Crops of the Veins, with their various Thicknesses.		
North Crop.	South Crop, North of Anticlinal.	South of Anticlinal.	Crops.	ft.	in.
Coal. Stinking vein.	Wythien Drew-llyd. Penrhys vein. Pwll Robin vein. Coal. ,, ,,	Coal. Cilddoidy vein.	North crop .. .. South crop (north of anti-clinal) .. .. South of anticlinal .. .. Doubtful, and under the sea Plan No. 11 . ..	3 9 7 9 —	6 0 2 0
Coal. William's vein.	Cistern vein. Sulphur vein. Rotten vein. Hughes vein.	Bettws Fach vein. Bettws Fawr vein.	North crop .. .. .. South crop (north of anti-clinal) .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 12 .. .	3 13 14 13 —	6 8 1 8
Coal. ,, Presgyrch.	Shenkin vein. Six Feet vein. Three Feet vein. Two Feet vein.	Nil.	North crop .. .. .. South crop (north of anti-clinal) .. .. .. South of anticlinal .. .. Doubtful, and under the sea Plan No. 13	7 12 — 12 —	8 1 1
Coal.	Five Feet vein.	Nil.	North crop .. .. .. South crop (north of anti-clinal) .. .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 14 .. .	4 4 — 4 —	0 9 9
Carnarvon vein. Carnarvon New vein. Penbryn vein. Coal. ,,	Carnarvon vein. Carnarvon New vein. Penbryn vein. Four Feet vein. Two Feet vein	Nil.	North crop, 9,860 acres .. Ditto .. .. South crop (north of anti-clinal), 8,156 acres .. Ditto .. .. South of anticlinal .. .. Doubtful, and under the sea Plan No. 15	8 5 8 5 — 5 —	0 3 0 8 8

Coal Seams of the South Wales Basin—continued.

Name in ascending Order of each Seam or Vein of Coal, One Foot and upwards in Thickness, contained in each Plan.			Distinguishing the respective Crops of the Veins, with their various Thicknesses.	
North Crop.	South Crop, North of Anticlinal.	South of Anticlinal.	Crops.	ft. in.
Rosy vein. Fiery vein. Golden vein. Bushy vein.	Rosy vein. Fiery vein. Golden vein. Bushy vein.	Nil.	North crop .. .. .. South crop (north of anticlinal) .. .. .. South of anticlinal .. . Doubtful, and under the sea Plan No. 16 ..	9 0 9 0 — — —
Coal. ,, ,, ,,	Penscallen vein. Little vein. Broad Oak vein. Glyngwernen vein.	Nil.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. .. Doubtful, and under the sea Plan No. 17 . ..	13 8 13 8 — — —
Upper vein. Wythien Ffraith. Wythien Spagog. Gelly vein, or Wythien Drewllyd.	Upper vein. Wythien Ffraith. ,, Spagog. Gelly vein, or Wythien Drewllyd.	Nil.	North crop .. .. .. South crop (north of anticlinal) .. .. South of anticlinal .. Doubtful, and under the sea Plan No. 18 . ..	11 0 11 0 — — —

in which Swansea is situated, with an area of 94 square miles, the coal is bituminous. This coal underlies a large portion of Swansea Bay.

These successive bands range approximately from west to east—expanding in breadth in the latter direction—and are continued eastward into the central district.

Ironstones.—The Lower measures are the chief repositories of ironstone, as at Merthyr Tydvil, and at Taffe

Vale, near Cardiff. They are seldom more than 5 inches in thickness, and frequently contain marine shells, fish, and plants. The following is an analysis of the principal bands, made at the Museum of Practical Geology :—

Analysis of Ironstones.

	Carb. Iron.	Earthy Matter.	Metal.
Upper vein, Ystradgynlas ...	86·0	14·0	41·5
Another vein, ,, ...	72·4	27·6	34·9
Cwm Phil vein	75·4	24·6	36·4
Pendaren Red vein	75·4	24·6	36·4
,, Jack ,, ...	55·5	44·5	26·6
Black-band, Pontypool ...	79·5	20·5	38·4

The yield of these Coal-measure ores, even in conjunction with the hæmatite from the Carboniferous Limestone, is sometimes not sufficient to supply the enormous consumption, and large quantities are imported from Spain.

Faults.—The fractures which traverse the South Wales coal-field are, in the great majority of cases, referable to one system, nearly perpendicular to the longitudinal axis of the basin, and therefore ranging from N.N.W. to S.S.E. A very few range from east to west. The remarkable parallelism of these fractures, and their direction with reference to the general arrangement of the strata, leave no doubt that they have all resulted in one system of disturbing forces.

Fossils.

The ironstones and shales of the Upper and Middle Coal-measures contain, as already stated, shells chiefly of the genus *Anthracosia* ; but when we descend into the

lower strata which overlie the Millstone Grit, we find a series of mollusca, closely resembling, and sometimes identical with, those of the Lower Coal-measures or "Gannister Beds" of the north of England. They are contained generally in the ironstone bands, and were determined by the late Mr. Salter from the collection of Dr. Bevan.*

1. Top.—Black-band ironstone. Fish: *Rhizodus*, *Megalichthys*. Shells: *Modiola*.
2. *Soap Vein*.—Tracks of *Annelids*, and a new genus of bivalve shells peculiar to the coal-measures.—*Anthracomya*.†
3. Ironstone above "3-quarters Coal."—*Anthracomya*.
4. Ironstone over Bydyllog Coal.—*Athyris planosulcata*: a shell also found in the Carboniferous Limestone.
5. Darin Pins Ironstone.—*Anthracosia*, *Anthracomya*, *Myalina* (same species as in the "Pennystone" band of Coalbrook Dale). *Avicula* (?).
6. Ironstone over "Engine Coal."—*Spirifer* and *Productus*.
7. "Old Coal" black band.—*Anthracosia acuta*, and *A. ovalis*, both common species in the coal-measures.
8. Spotted Vein.—Tracks of *Limulus*, a crustacean allied to the King Crab—and *Spirorbis carbonarius*.
9. Bottom Vein.—Fish: *Megalichthys*, *Rhizodus*, *Palæoniscus*, *Amblipterus*, *Pleurocanthus*, *Helodus*, *Pecilodus*, *Pleurodus*.
10. Bottom Rosser Vein.—Fossils of the Carboniferous Limestone. *Spirifer bisulcatus*, *Orthis resupinata*, *O. Michelini*, *Chonetes Hardrensis*, *Streptorhynchus crenistria*. *Productus semi-reticulatus*, *Edmondia Unioniformis*. *Axinus Carbonarius*. *Productus Cora*, *Conularia quadrisulcata*, *Nautilus falcatus*.

Entomostraca.—In certain black-band ironstone strata, lying about 30 yards above the "Rider Coal," in the Pennant series, Mr. W. Adams, of Cardiff, in 1869, dis-

* For description and figures of many of these fossils, see "Iron Ores of Great Britain," Part iii.

† Genus established by Salter. "Iron Ores of Great Britain," Part iii, p. 229.

covered some very interesting forms of Entomostraca, figured and described by Professor Rupert Jones, and associated with *Anthracomya Phillipsii.* Some of the species are new, and include the genera *Estheria*, *Carbonia*, and *Leaia.**

Coal-resources of the South-Wales and Monmouthshire Basin, 1903.

The preparation of these returns was entrusted to Sir W. Thomas Lewis, assisted by several qualified surveyors. Considering the interest taken in the question of our "steam coal" supplies, the extent of the export trade, and the demand for this class of coal both for British and foreign shipping, the returns will doubtless be scanned with special interest, and probably with satisfaction. I proceed to give the returns under several heads, beginning with the amount available to a depth of 4,000 feet, and over this depth.

1. *Quantity in Tons available to* 4,000 *feet.*

Depth.	Estimated quantity remaining unworked.	Total estimated deductions for all causes.	Net estimated quantity remaining for use.
Not exceeding 4,000 feet in depth from surface ...	33,443,000,339	6,972,003,760	26,470,996,579
Exceeding a depth of 4,000 feet from surface	2,279,864,081	415,072,510	1,864,791,571
Total at all depths ...	35,722,864,420	7,387,076,270	28,335,788,150

* Geol. Mag., vol. iii, p. 214 (1870).

2. *Summary of Estimated Available Resources in Seams 12 inches thick and upwards.*

Divisions of the Coal-fields.	Gross Tonnage.	Deductions.	Net Tonnage.
Monmouthshire	3,413,333,589	669,825,515	2,743,508,074
Glamorgan (East)	14,136,265,086	3,065,904,618	11,070,360,468
Glamorgan (West), Carmarthen, and part of Brecon	17,869,824,245	3,520,488,450	14,349,335,795
Pembrokeshire	303,441,500	130,857,687	172,583,813
Total	35,722,864,420	7,387,076,270	28,335,788,150

The *deductions* amount to 20·68 per cent. of the *gross estimate*, leaving the *net available quantity* equivalent to 79·32 per cent. of the *gross estimate*. The deductions include those due to thin coal-seams considered unworkable at great depths.

3. *Estimated Approximate Quantities of the various Classifications of Coal in the South Wales Coal-fields.*

Eastern Division.

	Tons.
Bituminous	4,588,476,542
Second Class Steam	5,027,088,000
First Class Steam	4,198,304,000
Total	13,813,868,542

Western Division.

	Tons.
Bituminous	4,135,202,423
Steam	4,076,424,971
Anthracite	6,310,292,214
Total	14,521,919,608

Eastern and Western Divisions.

	Tons	Per cent.
Bituminous	8,723,678,965	= 30·79
Steam	13,301,816,971	= 46·94
Anthracite	6,310,292,214	= 22·27
Total... ...	28,335,788,150	

4. *Estimates according to Counties at all Depths.*

Counties.	Total estimated quantity remaining unworked.	Total estimated deductions for all causes.	Estimated net available Quantity remaining unworked.
Monmouthshire	3,413,333,589	669,825,415	2,743,508,074
Glamorgan (East)	14,136,265,086	3,065,904,618	11,070,360,468
Glamorgan (West), Carmarthen, and part of Brecon	17,869,824,245	3,520,488,450	14,349,335,795
Pembrokeshire	303,341,500	130,857,687	172,583,813
Total	35,722,764,420	7,387,076,170	28,335,788,150

5. *Total Available Quantities of Coal in Seams of Various Thickness in the Counties.*

Divisions of the Coal-field.	At Depths not exceeding 4,000 feet from Surface.				
	Tons in Seams 12 to 15 inches thick.	Tons in Seams 15 to 18 inches thick.	Tons in Seams 18 to 24 inches thick.	Tons in Seams 24 inches and upwards.	Total Tons (93·42 % of the total at all depths).
Monmouthshire ..	208,647,243	165,314,335	185,253,625	2,184,292,871	2,743,508,074
Glamorgan (East)	477,744,233	417,442,712	997,270,951	9,173,996,572	11,066,454,468
Glamorgan (West), Carmarthen and part of Brecon	475,596,597	745,805,112	1,362,039,073	9,905,009,442	12,488,450,224
Pembrokeshire ..	7,991,250	—	55,494,825	109,097,738	172,583,813
Total	1,169,979,323	1,328,562,159	2,600,058,474	21,372,396,623	26,470,996,579
	4·4 %	5·1 %	9·8 %	80·7 %	100 %

From the above estimates, according to the return supplied by Sir W. T. Lewis, it will be seen that the available quantity of coal within a depth of 4,000 feet amounts to over

26,470 millions of tons, of which over 13,301 millions of tons belong to the valuable class of "steam coal" suitable for naval purposes. The output has rapidly increased in recent years; in 1880 it amounted to 21,203,743 tons; in 1890, 10 years later, to 29,372,853 tons; and in 1903, to 42,154,191 tons. It has thus more than doubled in 23 years. This coal is chiefly raised from collieries situated in the counties of Glamorgan and Monmouth, and is shipped from Cardiff, Llanelly, Barry, Newport, and Swansea, while large quantities are consumed for iron smelting, tin plate manufacture, railway fuel, and household purposes.

Some of the collieries are of great depth, of which the following may be specially mentioned:—the Albion at Pontypridd, 545 yards; the Avon at Abergwynfi, 511 yards; the Bedlinog, Dowlais, 565 yards; the Deep Navigation, Treharris, 718 yards; the Lady Windsor, Pontypridd, 593 yards; the Ferndale, No. 8 Shaft, 460 yards; the Penrikyder at Mountain Ash, 530 yards; and the Resolver at Neath, 540 yards. Some still deeper mines will come into operation in the near future. Some of the above mines are working coal at an additional depth of 100 yards, owing to the height of the land above that of the pits.

CHAPTER II.

BRISTOL AND SOMERSETSHIRE COAL-FIELD.

AT an unusually short distance from the base of that range of Oolitic escarpments which stretches in a deeply indented line from Gloucestershire to Dorsetshire, lies the Bristol coal-field.* The thick series of formations which in the midland counties intervenes between the Coal-measures and the Lias, are here, either greatly reduced in thickness, or altogether absent; and hence we may pass from the one formation to the other within a distance of 100 yards.†

The coal district is divided into two principal basins; the northern situated chiefly in Gloucestershire, and the southern chiefly in Somersetshire. This latter is by far the larger.

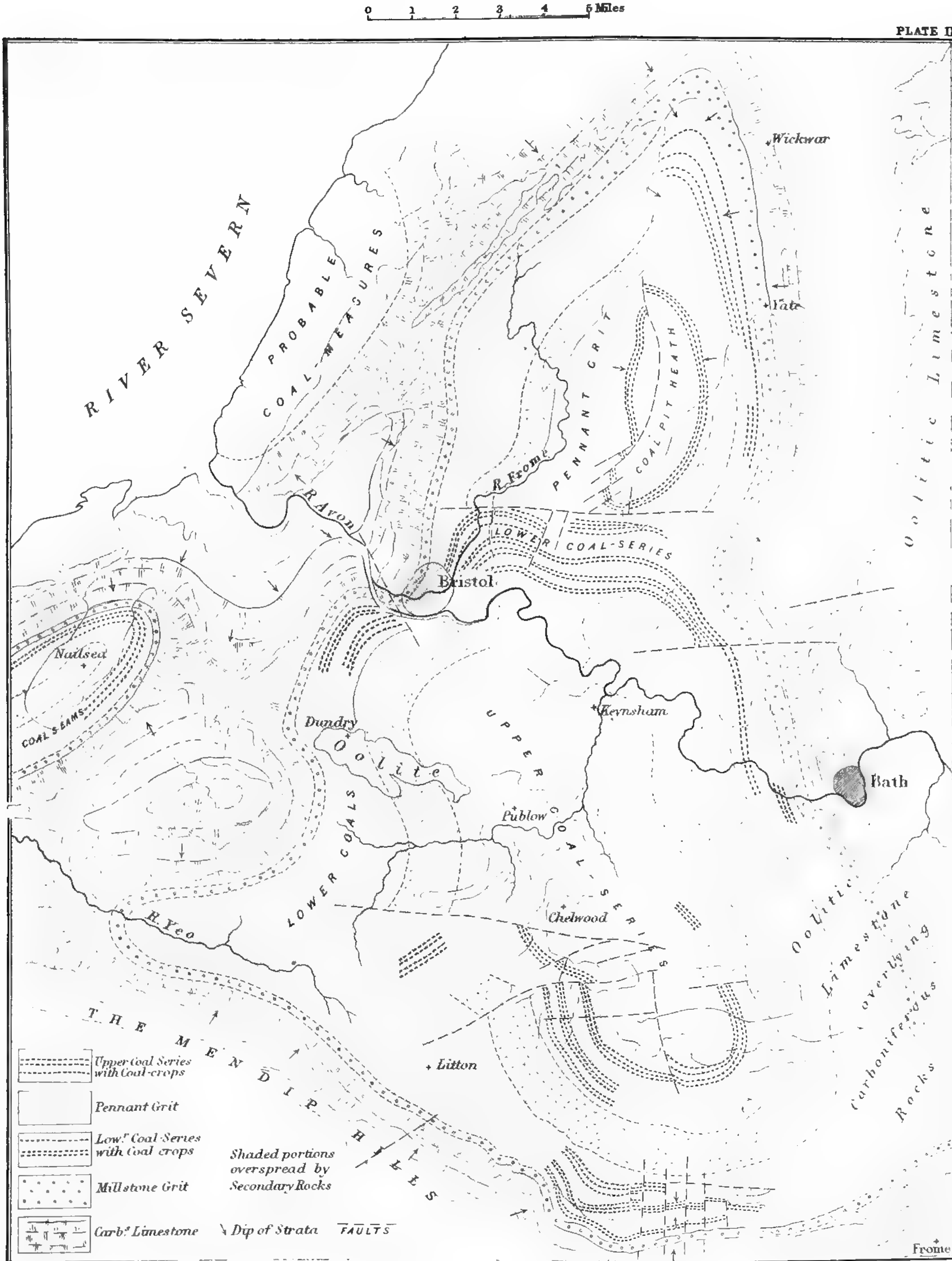
These basins are separated from each other by a broken, or faulted, anticlinal, ranging in an east and west direction, and crossing the River Frome about 2 miles north of Bristol. By this fault the "Pennant" Sandstone of the northern basin is brought into contact with the lower

* It ought to be stated that as early as 1730, Mr. Strachey described the coal districts of Somersetshire in a series of communications to the Royal Society, and from his sections it is evident he understood the relative positions of the Oolite, Lias, and Red Marl to the Coal-measures and limestone of the Mendips.

† This district is illustrated by the Geological Survey Maps 19, 35, and Sections, sheets 14, 15.

MAP OF THE
SOMERSETSHIRE
COAL-FIELD

PLATE II.



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measures which underlie that formation on the south side of the fault; there is thus a "downthrow," or relative lowering of the beds along the north side, as shown by the small map. The occurrence of the Pennant to the north of the fault has greatly retarded the development of the lower seams, which have been largely worked on the southern side of the anticlinal.

At Cromhall the coal-field terminates in an apex, from which it gradually expands in a southerly direction, till, east of Bristol, it reaches a width of 7 miles. Along, and beyond, the edge of the basin the beds rise at high angles. The Millstone Grit and Carboniferous Limestone form parallel belts, which range from the Mendip Hills to Tytherington and Cromhall. Upon the upturned edges of these more ancient formations the New Red Marl and Lias rest almost horizontally (see Section, fig. 6). South of Bristol, the boundary of the coal-field, marked by the range of limestone hills, sweeps round to the westward, and is lost under the sea beyond Nailsea Moor, near Clevedon, in Somersetshire. South of this the Coal-measures underlie the Liassic formations of Dundry Hill, and encircle the large mass of Carboniferous Limestone near Congresbury. Over the greater part of this area the coal-formation is buried at moderate depths under newer horizontal strata.

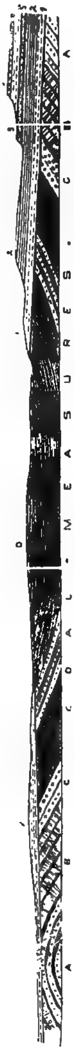


Fig. 6.—SECTION ACROSS THE BRISTOL COAL-FIELD.

A. Old Red Sandstone. C. Millstone Grit. 5. Lower Oolite.
B. Carboniferous Limestone. D. Coal-measures, with coal. 4, 3, 2. Upper, Middle, and Lower Lias
New Red Marl (Trias).

Along the southern boundary of the coal-field the Carboniferous Limestone of the Mendip Hills rises to the surface, trending from west to east, till lost beneath the Lias and Oolite, west of Frome. I was assured, however, by the late Mr. Etheridge, that the basin-shaped structure of the Carboniferous Rocks under the Lias and Oolite has been thoroughly established by actual sinkings and borings through these newer formations, so that the lowermost coal-shales, or Holcombe Series, do not pass eastward of a line joining Bath and Frome. On reaching Mells, the lowest beds bend round to the north, and take a course through Buckland, Norton St. Philip, Midford, Twiverton (where coal is worked), and North Stoke. It will be observed that this outcrop is in the line of the great north to south dislocation, which passes by Chipping Sodbury and Cleeve Bridge, near Doniton.*

The extreme length of this coal-field, from its northern apex at Cromhall to the flanks of the Mendip Hills, is 26 miles; the general strike of the beds north of the valley of the Avon being north and south, and over the area south of this line from west to east. About one-half of the northern basin is overlaid by nearly horizontal strata of the Triassic and Oolitic periods, and of the southern part nine-tenths are covered over in this manner; yet the existence of the underlying coal-field is abundantly proved, not only from theoretical considerations, but by actual sinkings for coal. Shafts penetrating the

* I was formerly of opinion, with many others, that the coal-field stretched eastwards from the Mendip Hills under the Oolites by Bath, Bradford, and Frome, until informed to the contrary by Mr Etheridge, who was well acquainted with the trials which have been made to prove coal in this direction. It is very probably, however, that the coal-measures roll in again under the Cretaceous rocks of the Vale of Wardour.

Lias and Red Marl into the coal have been sunk at Paulton and Timsbury; and another near Radstock, commencing in the Upper Beds of the Lias, reaches coal at 200 fathoms.*

The succession of strata in the neighbourhood of Bristol has been determined by Mr. D. Williams,† and is as follows:—

Succession of Strata near Bristol.

Lias ...	... Lower, Middle, and Upper Lias.	
Trias (*Keuper*)	Red Marl.	
	Dolomitic conglomerate.	
Coal-measures	Upper series, with 22 coal-seams, of which 9 average 2 feet in thickness and upwards	ft. 3,000
	Central or Pennant Sandstone, etc., 5 coal-seams ...	1,725
	Lower shales, 36 coal-seams	2,000
Millstone Grit	Hard siliceous grits, etc.	950
Carboniferous Limestone, well shown in the gorge of the Avon	...	2,338

There is thus a total thickness of strata with coal of 6,725 feet, separated into two divisions by a series of hard, flaggy sandstones (Pennant), which will prove a serious obstacle to sinking in search of the lower coals. Of the 63 coal-seams above mentioned only 20 are 2 feet and upwards in thickness, producing 71 feet of coal.‡

* "Lectures on Geology," by Mr. R. Etheridge, 1859. A little book containing much valuable information about the Bristol coal-field, and to its author I am indebted for many details concerning this district.

† "Mem. Geol. Survey," vol. i, p. 207.

‡ Sir J. Prestwich, F.R.S., one of the Commissioners (1871), drew up an able report on this coal-field, gives the number of seams as 46, with 98 feet of coal. The numbers and thicknesses of the seams depend of course very much on the part of the district where the section is taken. I have adopted Prestwich's estimates of thickness of the upper and lower coal-series.

The coal-measures were arranged by the late Mr. Etheridge under the following subdivisions :—*

Upper	... ...	Radstock series. Farrington series.
Middle	... ...	The Pennant series.
Lower	... ...	Bedminster series. Aston, or Holcombe Series.

The Radstock Series (see section, p. 74) occupies a small area in the southern part of the coal-field between Kilmersdon and Farmborough.

The Farrington Series forms a much larger area—from Holcombe on the south, to near Brislington on the north, and from Combe Hay on the east, to Chew Magna on the west.

The Bedminster Series encircles the last in a band about one mile and a half broad along the east, and on the west occupies the greater part of the flat ground around the limestone inlier of Congresbury and Backwell, stretching to the sea coast under Nailsea Moor, Kenn Moor, Nempnet, and Puxton. It also forms a greater part of the northern district.

The Lowest Series of Holcombe forms a narrow belt lying immediately over Millstone Grit or "Farewell Rock." Along the edge of the Mendips, and at Twiverton, the strata are highly disturbed and dislocated. The seams of the Lower Series decrease in number and importance, both southward at Nailsea, where they are reduced to 12, and northward to Yate and Cromhall, where only seven seams exist. They attain their fullest development in the central area.†

* "Lectures on Geology."

† Prestwich, "Report," p. 39.

According to Mr. Walter Saise, the Upper Measures furnish chiefly gas and house coals, the Middle or Pennant beds are noted for smiths' coal and good fire-clay, and the Lower for steam coal and associated ironstone.*

The following is the general succession of the coal series, for which I am indebted to Mr. Etheridge, and which is very similar to that published by the Geological Survey (see pp. 74 and 75).

Flexures and Faults.—The coal-field is divided into two principal parts by an anticlinal axis, which runs east and west through Kingswood, where it brings the coals of the Lower Series to the surface, and throws off the Pennant rocks on its flanks. The axis itself is parallel to a large fault already described, and is traversed by a number of faults, mostly of uncertain value, by which the workings of the coal-seams are interrupted.

Another great disturbance is one which raises the coal-measures into a vertical position along the northern base of the Mendip Hills, the axis of which is parallel to the former, and ranges east and west. Along this line the coal-measures are tilted vertically, and have in some cases a reversed dip, so that the coals can often be worked to a depth of 200 or 300 feet perpendicularly, the shaft following the course of the seam. The coal, especially when the dip is reversed, is generally much broken, and often so mixed with shale and stone as to be useless. In connection with this latter disturbance is the remarkable "slide fault," by which the upper portion of the Radstock Series has been thrust almost horizontally for a distance of 130 to 220 feet northward over the lower

* "Notes on the Bristol Coal-field," read before the Geological Section of the British Association at Bristol, 1875.

General Coal-series of the Somersetshire Coal-field.

North Side.			South Side.		
Name of Coal-seam, etc.	Ft.	In.	Name of Coal-seam, etc.	Ft.	In
New Red Sandstone and Marl at Coal Pit Heath	270	0	New Red Sandstone and Marl	120	0
			Dolomitic conglomerate ("millstone")	6	0
			Sandstone and shales	240	0
			Withey Mill Seam ...	1	0
Radstock Series.			Strata		
(Not represented in the Northern district.)			Great Seam of Clair Down	2	0
			Strata, with two thin seams	67	6
			Middle Seam... ...	1	8
			Strata	100	0
			Silven vein	2	6
			Strata...	40	0
Farrington Series. *Coal*	1	4	*Little Seam*	1	6
Shale and rock, with thin seams	102	0	Strata (*with Bull Seam, etc.*) ..		
Hard Seam	3	0			
Shale with coal, 1 foot	123	0	*Farrington Series.* *Sulphurous coal* ...	2	0
Hollybush Coal ...	3	0	Strata	36	0
Shales and Sandstone	52	0	*Cat-head Seam* ...	2	0
Great Seam (in three beds)	5	0	Strata	36	0
			Three-seam Coal ...	3	0
Strata, etc.	238	0	Shales, etc., with *Anthracosia* ...	54	0
Coal	1	6	*Peacock Coal*... ...	2	0
Strata	215	0	Shales	36	0
			Shaley Seam... ...	2	0
			Shales	36	0
*Pennant Series.** Hard sandstone, with a few beds of shale—and three coal-seams, each about 2 feet in thickness ...	1,500	0	*Pennant Series.** Principally hard sandstones, with five seams of coal	1,500	0

* Prestwich states that the Pennant Rock has been traversed to a depth of 800 feet, and has probably a mean thickness of not less than 2,000 feet. The following are the seams which it contains. In the Nettlebridge district, the "Globe Seam," 3 feet thick, of good quality. In the Bristol district, the

General Coal-series of the Somersetshire Coal-field—(contd.).

North Side.

Series	Name of Coal-seam, etc.	Ft.	In.
Bedminster Series.	*Cock Seam*	2	0
	Sandstone	42	0
	Hen Seam	1	6
	Strata	180	0
	Coal	2	6
	Strata	540	0
	Britton's Seam ...	1	2
	Strata	300	0
	Coal	3	0
	Strata	78	0
	Shelly Vein Coal ...	3	0
	Strata	54	0
Holcombe Series.	*Hard Seam*	1	7
	Sandstone and shale ...	360	0
	Coal	4	0
	Strata	60	0
	Great Seam	4	0
	Sandstone	60	0
	Coal		6
	Shale	120	0
	Coal	2	0
	Shale	48	0
	Slate Seam	1	8
	Shale	24	0
	Coal	1	0
	Strata	24	0
	Coal	1	0
	Sandstone	60	0
	Stoney Seam	1	4
	Strata	180	0
	Coal	4	0
	Millstone Grit ...	180	0

South Side.

Series	Name of Coal-seam, etc.	Ft.	In.
Bedminster Series.	*Small Coal*	3	0
	Dead Course, or Shell Seam	3	0
	Garden Course ...	3	6
	Strap Seam	2	6
	Great Course ...	4	0
	Firestone Seam ...	3	0
Holcombe Series.	*Dungy Drift* ...	2	0
	Hard Coal Drift ...	3	0
	Perkin's Course ...	2	0
	Foot Coal	2	0
	Branch Coal... ...	4	0
	Golden Candlestick ...	2	6
	North Sheets... ..	4	0
	Cat (red ash) ...	1	0
	South Sheets... ...	3	0
	Riband Coal... ...	1	2
	Standing Coal ...	4	0
	Fern Rag	2	6
	Stone Rag	3	0
	Callows Seam ...	4	0
	Penrick, or *Blackstone Coal*	3	0
	White-axen (ash) ...	2	6
	Firestone Seam	2	0
	Millstone Grit ...		

"Pig Seam," 10 inches; the "Millgrit Seam," 3 to 6 feet, a smith and steam coal; the "Rag Seam," from 1 to 4 feet; the "Devil's Seam," 2 to 4 feet, of uncertain quality.—"Report," 37.

Note.—The *terms* used at the sides of the columns are intended to show that the seams, in the North and South area of the coal-field, are most likely the same under different names, and are here attempted to be correlated.

portion.* To the south of Chelwood the beds are broken by several faults.

Outlying Basins.—Two outlying basins, situated to the north and south of the mouth of the Avon, have been proved to exist. One of these, partially submerged beneath the River Severn, has been discovered by borings, and the railway excavations at Almondsbury;† the other occurs at Nailsea, lying in an oval hollow surrounded by Millstone Grit and Carboniferous Limestone, where coal has been worked. Only the lower seams, reduced to 12 in number, are found in this latter basin, and they are partially concealed by the Red Marl formation. The positions of these basins are shown on the map (Plate II).

Fossils.—But few animal remains have been found in this coal-field, but bivalve molluscs (*Anthracoptera* and *Anthracosia?*) have been recorded from Tiverton and Camerton by Prof. Morris—and remains of *Entomostraca* (*Estheria striata*, *Beyrichia arcuata?*) from Nailsea, determined by Prof. T. R. Jones. Two specimens of Limulus have also been found by Mr. E. Feare.‡

Resources.

In attempting to estimate the future resources of this coal-field, great deductions are unquestionably necessary from the calculated quantity of coal, owing both to general and special circumstances. Besides excluding all seams below 4,000 feet in depth, we must, I think, omit many

* Prestwich, Report, vol. i, p. 60.

† These are described by Prestwich (*ibid.*, p. 164), who quotes Report of Mr. C. Richardson, C.E., to Bristol Chamber of Commerce.

‡ Geol. Mag., vol. v, pp. 356–7.

of those within this depth, owing to thinness and deterioration in quality. The Pennant Rock, which overspreads so large a portion of the Lower Series of coals, will also undoubtedly prove a serious obstacle, owing to the expense of sinking through it; while the contorted and crushed state of the coals along the southern borders of the field is likely to discourage working at great depths in that district.

Sir Joseph Prestwich, who, with the assistance of Mr. Anstie, has made an elaborate series of estimates for each parish, giving a grand total of over 6,000 millions of tons, has rightly appreciated the force of those special difficulties likely to attend future mining operations, and has made considerable deductions in consequence.

The returns, prepared by Sir W. Thomas Lewis for the Commission of 1904, are based on those of his predecessor, with exceptions as regards the parishes of Camely and Stowey, in which the Upper Seams were erroneously supposed to be included. Sir W. T. Lewis gives the total estimate within 9,000 feet in depth as 6,036,633,000 tons, of which 4 151,293,000 tons lie within the limit of 4,000 feet.

Estimate of Resources, 1903.

1. Area (of which only 45 square miles are not concealed by newer formations)	150 square miles.
2. Greatest thickness of measures with coal	9,000 feet.
3. Number of coal-seams from 2 feet and upwards, 20; giving a thickness of coal of	71 ,,
4. Total quantity of coal down to 9,000 feet ...	6,036 millions of tons.
5. After deductions for faults, barren ground, and for quantity below 4,000 feet, there remains available for future use	4,151,293,000 ,,

The output of coal from this coal-field in 1901 was 1,341,393 tons from about 60 collieries. It produces good house, rich gas, coking, manufacturing and steam coals.

Steam Coal of the Class used by the Admiralty.

Since the above was in type, Sir W. T. Lewis has given an estimate of the quantity of coal of the kind used by the ships of the Royal Navy still remaining to be worked from seams of 1 foot and 2 feet and upwards; neglecting the former, I give the quantity included in seams of 2 feet and upwards, amounting to 570,580,522 tons, of which 170,293,070 tons belong to collieries now working, and 400,287,452 tons are contained in unlet areas.

On the Prospects of Coal South of the Mendip Hills.

Along their southern margin, the Carboniferous Limestone which forms the main mass of the Mendip Hills dips to the southward, through a tract of country ranging from Worminster and Westbury to Pleadon. The district to the south—forming the valley of the River Brue—is overspread by alluvial and Mesozoic strata, consisting of Lias and New Red Marl, through which some abortive attempts have been made to reach coal beds.* The Carboniferous Limestone of Cannington Park may be considered to indicate the southern boundary of the possible basin. For many years past geologists have inferred the existence of a concealed coal-field ranging under the valley of the Brue westward into and beneath

* Described by Messrs. Bristow, F.R.S., and H. B. Woodward, Geol. Mag., November, 1871. Mr. Bristow records the presence of Millstone Grit at Priddy and Dinder.

the Bristol Channel.* The rising up of the Mendip Ridge, which is a broken arch, or anticlinal axis, bounded both to the north and south by similar low-lying tracts, covered by Mesozoic strata, induces us to infer similar geological conditions on either side. The presence of coal-measures along the northern margin of the ridge we know to be a fact; and we, therefore, infer their presence beyond the southern margin. Assuming this to be the case, we have to recollect that (as Sir J. Prestwich observes) the Mesozoic rocks on the south of the Mendips are probably of greater thickness than they are to the north, and Sir R. Murchison has shown that the existence of the Culm-measures of Devonshire points to a rapid deterioration of the coal-measures in that direction. Probably as long as coal can be reached with such comparative ease in the Bristol district, that of the Brue Valley, supposing it to exist, will not be perseveringly essayed. Meanwhile it may be affirmed that the evidence is in favour of the supposition of a concealed coal-basin containing seams of inferior quality.

* Ramsay, Mem. Geol. Survey, vol. i, p. 305; Prestwich, Report, vol. i, p. 163; Bristow, *op cit.*, p. 4.

CHAPTER III.

FOREST OF DEAN COAL-FIELD, GLOUCESTERSHIRE.

THE structure and resources of this little coal-field are now thoroughly understood. It forms a more perfect "basin" than any other coal-field in England; as the strata everywhere dip from the margin towards the centre, except at one part of the western side, where the oval outline is interrupted for a short distance.*

The Coal-measures are surrounded by belts of Millstone Grit and Carboniferous Limestone, which generally rise considerably above the tract of the Coal-measures they enclose, just as the banks of a lake are higher than the lake itself; and the Carboniferous Limestone in turn rests upon a bed of Old Red Sandstone.† The general structure resembles that of the South Wales coal-basin in miniature.

Scenery.—The scenery around the skirts of this coal-basin is rich and varied. The eastern ridge of the Carboniferous Limestone overlooks the Vale of the Severn, and commands the escarpment of the Cotswold Hills of Gloucester and Somerset. At the opposite side of the coal-field the eye rests upon the Vans of Brecon, 2,700 feet in height, and the ranges which mark the northern bounds

* The Royal Forest covers a space of 23,000 acres, of which 11,000 are in timber. Deer formerly abounded, but are now almost extinct.

† See Maps of the Geological Survey, 43, S.E. and S.W., and Mr. Sopwith's large map in the Museum of Practical Geology.

of the great South Wales coal-field. The limestone ridge on which you stand is cut into lofty cliffs lining the gorge of the Wye, and in its extension southwards towards Chepstow produces those remarkable terraces which render the scenery of that part of the river as beautiful as it is peculiar.

The area of the coal-field is about 34 square miles. It contains 15 seams of coal, of which only eight are of a thickness of 2 feet and upwards; and the total series, as stated by Sir H. de la Beche, is as follows:—*

	Ft.
1. Coal-measures, with 15 coal-seams	2,765
2. Millstone Grit	455
3. Carboniferous Limestone	480
4. Lower Limestone Shale	165
5. Old Red Sandstone	8,000 or more.

In the Carboniferous group there is a decrease by two-thirds in the thickness of the strata as compared with the Bristol district. Over the centre of the basin the strata lie nearly horizontally. On approaching the eastern borders they rise very rapidly; but along the opposite, or western edge, the lower beds spread out considerably, and in consequence have a much larger horizontal range than those higher up in the series. The coals are being gradually worked from the margin of the basin, where they crop out, towards the centre, where they are deep; on which account it is probable that progressive mining operations will be much hindered by the accumulation of water in the old workings.

* Mem. Geol. Survey, vol. i, p. 203.

Succession of the Coal-seams.

	Ft.	In.
Sandstones and shales with thin coals	830	0
Cow Delf	0	8
Strata	91	10
Dog Delf	1	2
Strata	46	9
Smith Coal	2	6
Strata	34	6
Little Delf	1	8
Strata	48	8
Park End High Delf	3	7
Strata	56	0
Starkey Delf (with parting)	2	0
Strata	50	0
Rocky Delf	1	9
Strata	77	6
Upper Churchway Delf (with partings)	1	11
Strata	34	0
Lower Churchway Delf	1	6
Strata	150	0
Braizley Delf	1	9
Strata	430	0
Nag's Head, or *Yorkley Delf*	2	9
Strata	153	0
Whittington Delf	2	6
Strata	137	0
Coleford High Delf (variable)	2 ft. to 5	0
Strata	124	0
Upper Trenchard Delf	2	0
Strata	72	0
Lower Trenchard, or *Bottom Coal*	1	4

Many of the coal-seams are exceedingly variable in thickness and quality, as I know by painful personal experience. The Coleford High Delf is subject to rapid fluctuations in thickness, and is so soft that only about 2 feet can be extracted as large coal, the rest being slack or small.

The Forest of Dean in 1878 contained nine iron furnaces,

of which two were in blast, producing upwards of 40,000 tons of pig-iron. The ore used is derived from the clay-ironstone of the coal-measures, from brown hæmatite extracted from the Carboniferous Limestone, and from other extraneous sources.*

The Horse.—In one of the coal-seams, called "Coleford High Delf," there occurs one of those interruptions in the regular course of the strata, which tend to throw much light on the original conditions under which coal was formed, but are an occasion of serious loss and disappointment to the proprietor. River channels filled with sand, traversing coal-seams, occur in almost every coal-field, and are known as "rock-faults" and "horse-backs"; but the case here alluded to is so remarkable, and has been so fully investigated, that it will serve as a general illustration of these phenomena in other districts.† The description is by Sir H. de la Beche,‡ who says:—The "horse" with its branches resembles a channel cut amongst a mass of vegetable matter in a soft condition. It ranges S. 31° E. for a length of 2 miles, and a breadth of 170 to 340 yards. A number of minor channels communicating with each other and the main channel are named "Lows"; Mr. Buddle compares the *horse* to the bed of a river, and the *lows* to smaller streams cutting only a lesser depth,

* The brown hæmatite accompanies the Carboniferous Limestone, which nearly encircles the coal-field, and was worked by the Romans during their occupation of Britain. In 1869 there were extracted 172,023 tons.—Hunt, Mineral Statistics, p. 64.

† Mr. Jukes has very fully described these *horses* or *rock-faults* in the "Thick Coal" near Dudley, in his "Memoir on the South Staffordshire Coal-field," p. 45.

‡ "Mem. Geol. Survey," vol. i, p. 156.

The channels are filled principally with sandstone, which extends over the coal-seam, and forms its roof.

Resources (1903).

1. Area of coal-field	34 square miles.
2. Greatest thickness of coal-measures	2,760 feet.
3. Number of coal-seams from 2 feet and upwards, eight, giving a total thickness of ...	24 ,,
4. Total available quantity of coal (corrected for pillars, faults, and other sources of loss)	258 millions of tons.

CHAPTER IV.

COAL-FIELD OF THE FOREST OF WYRE, WORCESTERSHIRE.

A COAL-FIELD of about as large a superficial extent as that of the Forest of Dean stretches from the northern end of the Abberley Hills and, spreading out under the Forest of Wyre, ultimately becomes contracted northwards to a narrow band lining the banks of the Severn south of Bridgenorth.

The Coal-measures repose on a bed of "Old Red Sandstone,"* consisting of red marls, sandstones, and cornstones (concretionary earthy limestones), and are overlaid by a thick mass of Lower Permian strata, composed of red sandstones and marls with calcareous conglomerates, and marly breccia,† very fully developed at Enville. This Permian breccia has excited much interest regarding its origin; for Prof. Ramsay has shown that it bears a strong resemblance to accumulations originating in glaciers, and spread over the sea-bottom by floating ice; such as that of the Boulder clay of the Glacial epoch. If this theory be correct, a vast change must have come over the climate

* Really, as I believe, "Estuarine Devonian." See Quart. Journ. Geol. Soc., May, 1880, p. 268.

† "Breccia" is a word used to designate strata formed of angular pebbles; "conglomerate" being confined to strata in which the pebbles are rounded or water-worn.

of these countries between the Coal Period and that which immediately succeeded it.

This coal-field has not been fully explored; but, as far as is known, the coal-seams which it contains are both thin, and of inferior quality. The following series occurs near the western margin, as exhibited in the late Mr. Aveline's section drawn across this district.*

Section of Coal Strata, Forest of Wyre.

	Ft.	In.
1. Sandstone and shale	76	0
2. Coal	1	10
3. Sandstone and shale	24	0
4. Coal	2	0
5. Sandstone and shale	39	0
6. Coal	4	0
7. Sandstone, shale, etc.		

Section at Harcott Colliery, Clee Hill Common, Forest of Wyre.†

Upper Series.

	Ft.	In.
1. Coal-measures	157	0
2. Blue Bind	6	0
3. Coal	1	0
4. Measures	26	0
5. Black Shale...	1	0
6. Measures	100	0
7. Coal	1	3
8. Measures	12	0

* Sections of the Geol. Survey, Sheet 50; also Geol. Map, 55, N.E.

† Extracted from a valuable paper by Mr. Daniel Jones, F.G.S., "On the co-relation of certain Carboniferous Deposits of Shropshire," in which he endeavours, not unsuccessfully, to explain the changes which have taken place in the beds from Coalbrook Dale, Harcott, Brown Clee, and Cornbrook.—"Geol. Mag.," vol. viii, p. 363 (1871).

Unconformity.

		Ft.	In.
9.	Black Parting	0	6
	Lower Series.		
10.	Measures	5	0
11.	Sweet Coal	4	6
12.	Ironstone and rock...	3	0
13.	Coal	0	9
14.	Clod	0	6
15.	Coal	1	8
16.	Black Clod and large balls of ironstone ...	5	0
17.	Coal	6	0
18.	Clod	2	6
19.	Coal	2	6

A coal-seam described as being "sound, bright, and semi-bituminous" has recently been reached at a depth of 305 yards at Highley.* This seam is known as "the Stanley Coal," and has a shale roof and fire-clay floor. Above it is the "main coal," 7 feet 6 inches in thickness, the bottom part, 4 feet thick, being of good quality. As these seams have a considerable horizontal range, the mineral prospects of this district seem to be of a fair character.

The strata of which this coal-field is composed represent chiefly the Upper Coal-measures, which seldom contain beds of coal of much value or thickness. One bed, however, varying from 4 to 5 feet, has been traced by the late Mr. G. E. Roberts over a considerable extent of the central part of the coal-field. The absence of the lower portion of the formation may be accounted for on the supposition that this part of England was dry land till near the close of the Carboniferous epoch.

* Mr. W. Molyneux, "Mining Journal," November 15th, 1879.

In a paper read by Mr. Daniel Jones before the South Staffordshire Institute of Mining Engineers (1894) the author has correlated the coal-series of the Forest of Wyre and South Staffordshire, and shows that the Harcott and Kinlet-Main coals are the representatives of the "deep" and "shallow" seams of Cannock. These seams belong to the lower series of "sweet" coals, in contradistinction to the "sulphur" seams of the upper series.

Fossils.—Mr. Roberts has brought to light several interesting particulars regarding the fossils, both animal and vegetable. In a band of limestone, apparently synchronous with that in the Upper Coal-measures of Coalbrook Dale, Warwickshire, and elsewhere, he has found fish-teeth and scales, *Leperditia inflata*, *Spirorbis carbonarius*, and fine specimens of *Posidonia*, determined by Prof. Rupert Jones. But perhaps the most interesting palæontological objects obtained by Mr. Roberts, are specimens of *Pecopteris* and other ferns retaining their fructification.*

At Arley Colliery, near Bewdley, the strata have been penetrated to a depth of 454 yards, ultimately reaching a mass of basaltic rock. Only one workable coal, at a depth of 176 yards, appears to have been found.

* For further details see Mr. Roberts' "Rocks of Worcestershire."

CHAPTER V.

SHREWSBURY COAL-FIELD.

THIS coal-field forms a narrow band extending from the base of Haughmond Hill, east of Shrewsbury, to the banks of the Severn near Alberbury, a distance of about 18 miles. Like the coal-field of the Forest of Wyre, the coal-strata repose on the older rocks without the intervention of the Millstone Grit and Carboniferous Limestone; but in this instance the fundamental rocks belong to the Cambrian and Lower Silurian periods. Notwithstanding its length, it is seldom more than a mile in breadth; and in its lower part contains two or three coal-seams which have been worked to a small extent, but are not of sufficient value to induce mining operations far from the outcrop.

The coal-measures are overlaid by Lower Permian strata, consisting of red and purple marls and sandstones, surmounted at Alberbury and Cardeston by a remarkable stratified breccia, composed of angular fragments of white quartz, and Carboniferous Limestone, cemented by calcareo-ferruginous paste.* The "Alberbury breccia" may be regarded as the remnant of an old shingle beach formed round a coast-line, composed of Carboniferous and Silurian rocks.

In the upper part of this coal-field a band of limestone†

* Sir R. I. Murchison, "Silurian" System, p. 63.

† This limestone is described by Sir R. I. Murchison, "Siluria," p. 321.

occurs with estuarine and marine organisms, some of which were at first supposed to be of fresh-water origin. It contains a small crustacean, *Cythere*, a bivalve shell, *Anthracosia*, and an annelide, *Spirorbis carbonarius*. Now it is a remarkable instance of the persistency of some calcareous strata over large areas, that this band of limestone, seldom more than a foot in thickness, can be traced in the coal-measures of Coalbrook Dale and the Forest of Wyre southward, those of Lancashire northward, and of Warwickshire eastward, representing an area of about 10,000 square miles; and throughout this expanse it is always found associated with those uppermost coal-strata, which preceded the introduction of the Permian rocks.

The coal-fields of the Forest of Wyre, the Clee Hills, and Shrewsbury, together with a fourth district extending from the base of Caer Caradoc to within a few miles south of Shrewsbury, are of so small a value in regard to their coal deposits, that it is not considered necessary to attempt an estimate of their resources. They have all been formed in the vicinity of old land-surfaces, and around lines of coast composed of more ancient rocks. The strata themselves belong generally to the higher part of the coal-series, which throughout England is but sparingly enriched with beds of coal. Their relations to the coal-measures of Coalbrook Dale have been carefully worked out by Mr. Daniel Jones.*

The Coal-fields of the Clee Hills, Salop.

Two small outlying coal-tracts, remnants of a formation which once spread continuously from South Wales and

* "On the co-relation of the Carboniferous Deposits of Cornbrook, Brown

Gloucestershire, are perched on the summits of the Titterstone and Brown Clee Hills in Shropshire, at a height in the latter case of 1,780 feet above the sea; the combustible materials with which they are stored, would serve as beacon-fires for many a mile around.

These coal-fields are rather more than a mile each in diameter, and are capped by a bed of hard basalt, to which, owing to its power of resistance to agents of denudation, the hills probably owe their preservation. On these flat-topped hills are planted several small collieries, whose shafts pierce the basalt before entering the coal. The vent from which this igneous rock has been erupted is situated in the Titterstone Clee Hill; and from this orifice the basalt has apparently been poured forth in the form of liquid submarine lava, at some period after the coal-measures were formed.* The thickness of the coal formation is but small, containing only two or three thin coal-seams, and the strata generally rest directly on Old Red Sandstone; but representatives both of the Carboniferous Limestone and Millstone Grit are interposed at the eastern side of the Titterstone Hill.

I have referred to these districts more on account of their geological interest than for any economical value they may be supposed to possess.

Clee, Harcott, and Coalbrook Dale."—Geol. Mag., vol. viii, p. 363 (August, 1871).

* See Horizontal Section of the Geological Survey, Sheet 36.

CHAPTER VI.

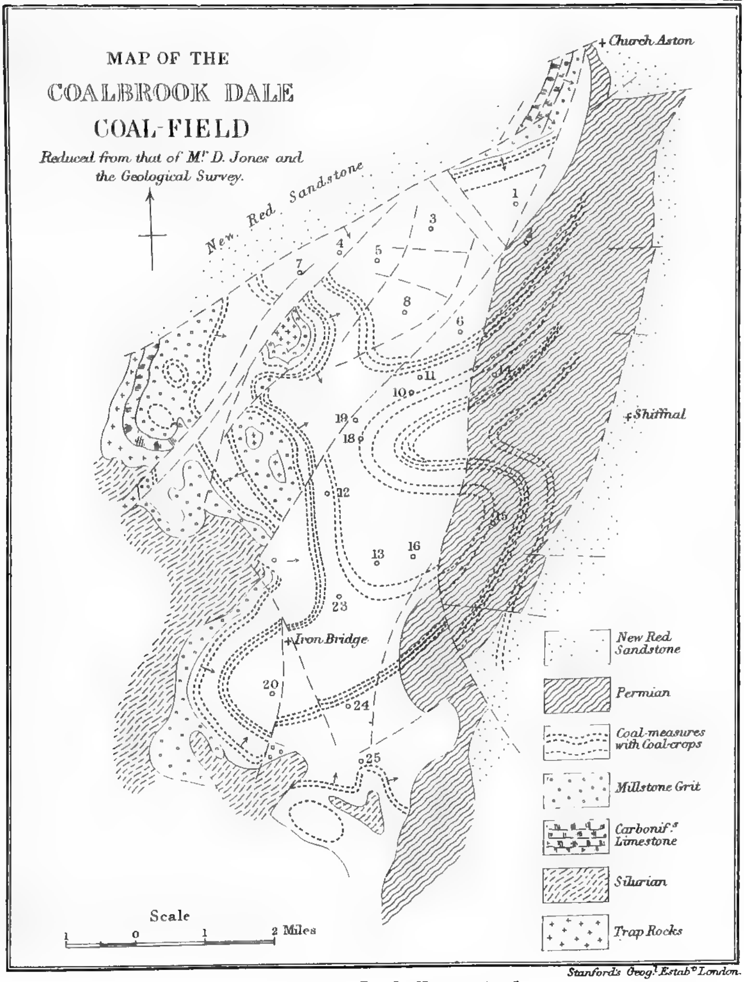
COAL-FIELD OF COALBROOK DALE, SHROPSHIRE.

THIS coal-field has a triangular form, with its base in the valley of the Severn, near Coalbrook Dale, and its northern apex at Newport. Along its western side it is bounded partly by a great fault, which brings in the New Red Sandstone, and partly by the Silurian rocks of the Wrekin, rising with its smooth and arched back to the height of 1,320 feet above the sea, and half that amount above the general level of the country around. Along its eastern side the coal-field is bounded by Permian strata, under which the Carboniferous beds appear to pass, but diminished both in thickness and in productiveness of coal.

The general dip of the strata is eastward; and in making a traverse to the foot of the Wrekin we cross in succession the base of the coal-measures, the Millstone Grit, Carboniferous Limestone, a bed of basalt, and at length reach Silurian rocks, which form the general foundation to the Carboniferous formations in this district. This succession of strata is illustrated by the section (Fig. 7, p. 94), in which, however, the denudation of the lower measures, and their overlap by the upper, is omitted; the drawing being too small for the insertion of these phenomena.

Surveys and Descriptions.—This coal-field is alluded to by the late Sir R. Murchison,* who notices some of its

* "Silurian System," p. 86, 1839.



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peculiarities; and is the subject of an elaborate memoir by Sir J. Prestwich,* accompanied by a map and numerous sections. It was afterwards surveyed by the officers of the Geological Survey.† More recently additional light has been thrown on its structure by Mr. Marcus W. T. Scott,‡ Mr. Randall,§ and Mr. D. Jones.‖ The researches of these gentlemen have thrown much light on the nature of the "Symon fault," and the relations of the Upper to the Lower Coal-measures, and of the Permian rocks to both.

Succession of Coal-seams, Coalbrook Dale.

			Ft.	In.		Ft.	In.
1. Chance Pennystone Coal	*(Found only at north end of coal-field.)*						
2. Fungus Coal ...							
3. Gur Coal							
4. Top Coal		from	4	0	to	4	6
5. Half-Yard Coal						1	6
6. Double Coal		,,	5	0	,,	6	0
7. Yard Coal...		,,	2	6	,,	3	0
8. Big Flint Coal		,,	3	0	,,	4	6
9. Stinking Coal		,,	3	0	,,	4	0
10. Clunch Coal						2	0
11. Two-Feet and Best (with parting)						3	4
12. Randle and Clod Coal		,,	4	0	,,	5	0
13. Little Flint Coal...		,,	1	6	,,	2	3

The whole of the above seams of coal are contained in a series of strata about 1,000 feet in vertical thickness.

* "Geol. Trans.," 2nd series, vol. v, 1840.

† Geol. Survey Maps, 61, N.E., and Horizontal Section, Sheets 54 and 58, with explanatory notices.

‡ "Journ. Geol. Soc.," London, vol. xvii, 457, 1861.

§ Letters published in the "Mining Journal," 1871.

‖ "Geol. Mag.," vol. viii, p. 200, 1871.

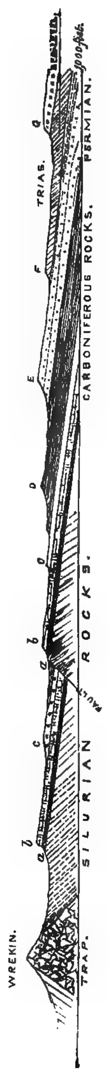


Fig. 7.—SECTION ACROSS THE COAL-FIELD OF COALBROOK DALE.
Distance about 5 miles.

D. Coal-measures, with coal.
c. Millstone Grit.
b. Carboniferous Limestone.
a. Basalt.
E. Permian Rocks.
F. G. New Red Sandstone. { G. Conglomerate. F. Lower Mottled Sandstone.

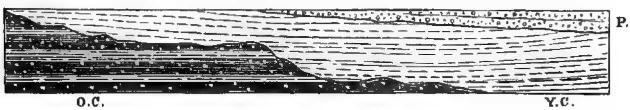
The Symon fault; denudation of the Middle and Lower Measures.—At the time when Prestwich was engaged in his investigations, it was known that several of the seams of coal and ironstone had a very limited range, and appeared to die out in certain directions. Thus it appears that the three uppermost seams in the above list of coals are only found in the northern part of the coal-field; that the Top Coal and Yard Coal are limited to the central portions; and finally, that the upper measures with the "Spirorbis limestone" are found at the southern end of the field, within 170 feet (vertically) of the base of the coal-measures.

The observations of Messrs. Scott and Jones appear very satisfactorily to account for these peculiar conditions. According to their views, founded on actual knowledge of pit-sections and underground works, there has been a considerable amount of denudation of the coal-series at a certain stage of the coal-period, and after all the strata up to, and including, the "Chance Pennystone" had been formed. In the hollow portions of the coal-field thus formed, the Upper Coal-measures appear to have been deposited; their

junction with the older strata being a sloping bank, or cliff, and the line of separation being marked by the presence of a bed of gravel and a mottled clay locally known as "Calaminker." The relations of these different portions of the same formation will be better understood by reference to the section below (Fig. 8), taken from Mr. Jones's paper, and by the Sketch Map, Plate III.

Upper Coal-measures.—These strata are found extending from the northern portion of the coal-field along the eastern side to the banks of the Severn, and consist of mottled clays, greenish grits, and calcareous gravel or

Fig. 8.—SECTIONS SHOWING RELATIONS OF THE MIDDLE AND UPPER COAL-MEASURES, COALBROOK DALE.



O.C. Older Coal-measures. Y.C. Younger Coal-measures. P. Permian Beds.

breccia, resembling volcanic ashes. In these beds the remarkably persistent band of compact limestone, with *Spirorbis carbonarius*, first described by Sir R. Murchison, is found, and has been traced southwards along the valley of the Severn into the coal-field of the Forest of Wyre. The boundary with the Permian rocks along the east appears, in some places at least, to have the character of an inclined bank, due to denudation.

The strata of this coal-field are much broken by faults. The largest of these is the western boundary fault; another, the *Lightmoor fault*, traversing the centre of the coal-field from north to south, has a "throw" of about 100 yards:

west of this fault the coal-beds are almost exhausted. There are also many transverse fractures.

Organic Remains.—These are extremely varied, and have been enumerated in detail by Prestwich. They occur principally in the ironstones, of which the principal depositories are the Pennystone and Crowshaw bands. Fish: *Hybodus, Gyracanthus formosus, Cochliodus, Megalichthys Hibberti, Pleuracanthus.* Crustacea: *Limulus*, a genus allied to the king-crab; *Glyphea, Leperditia inflata* (Bean). Mollusca: *Nautilus, Orthoceras, Bellerophon, Conularia, Spirifer bisulcatus, Productus scabriculus, Aviculo-pecten, Anthracosia* (Unio), *Ctenodonta* (or *Nucula*), *Lingula, Rhynchonella.* Insects: one or more species of scorpion; two beetles of the family *Curculionidæ,* and a neuropterous insect, resembling the genus *Corydalis*, and another related to the *Phasmidæ.**

There are several courses of ironstone measures, which in 1878 yielded 80,965 tons of pig-iron, from 11 blast furnaces;† the Coalbrook Dale and Lilleshall companies being the largest producers.

The coal under a very large portion of this field has been nearly exhausted, as will be apparent to any one who crosses it by the Wolverhampton and Shrewsbury railway, where over a large area, dismantled engine-houses, and enormous piles of refuse from abandoned coal and iron mines, meet the eye. The collieries have gradually migrated from the western outcrop towards the east. Under these circumstances, it is probably within the mark to deduct from the original mass of coal two-thirds for the quantity already worked out. Nearly 20 years back, when

* Lyell, "Elem. Geol.," p. 388.
† "Mineral Statistics," 1878.

Mr. Prestwich was engaged in his survey, the district west of the Lightmoor fault was almost destitute of coal.

Resources (1903).

1. Area of the coal-field	18 square miles.
2. Greatest thickness of coal-measures	1,300 feet.
3. Number of coal-seams of upwards of 2 feet in thickness, six, giving a total thickness of ...	27 feet of coal.
4. Estimated available quantity of coal for future use	153,097,130 tons.
The quantity of coal raised in 1903 amounted to ...	781,599 tons.

This estimate only applies to the actual coal-field. As already stated, the Coal-measures pass under Permian and New Red Sandstone along the eastern margin, and already have these rocks been invaded by at least three collieries, namely, the Granville Pits, the Stafford Pits, and the Kemberton Pits.

CHAPTER VII.

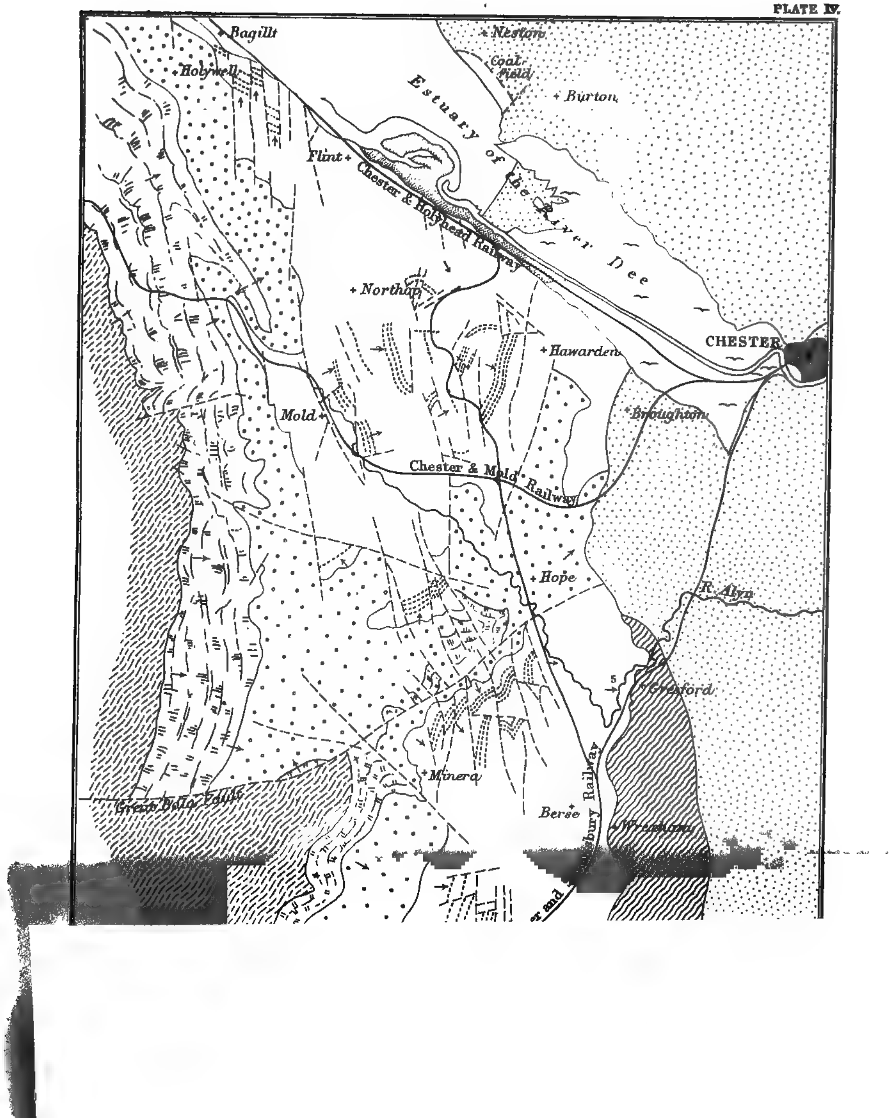
THE COAL-FIELDS OF NORTH WALES.

General Structure.

An interrupted tract of coal-measures extends from the northern slopes of the valley of the Severn, south of Oswestry, to the mouth of the estuary of the River Dee, in Flintshire, crossing the river at the entrance to the Vale of Llangollen. The coal-measures are overlaid by Permian strata on the south, and New Red Sandstone on the north, and repose on beds of Millstone Grit, Yoredale Shale, and Carboniferous Limestone, each about 1,000 feet in thickness.* These form a range of lofty hills with terraced escarpments looking westward, and exhibit a very noble and striking feature when viewed from behind Llangollen, where they assume the form of a long line of ramparts, the strata being piled up like lines of masonry, tier above tier. This rampart forms the physical line of demarcation between Wales and England, though the conventional boundary extends into the plain along the eastern slopes.

These calcareous hills are frequently traversed by faults, and are full of lodes rich in argentiferous galena ; the most

* The observations of Mr. Green of the Geological Survey ("Geol. Mag.," vol. iv, p. 11), and of Captain Aitken (*ibid.*, vol. vii, p. 263), tend to prove that a portion, at least, of the beds intervening between the Lower Coal-measures of North Wales are referable to the "Yoredale Series," as understood by the officers of the Geological Survey. Mr. D. C. Davies and Mr. W. Prosser have obtained numerous fossil shells, etc., from these beds.


Bagillt
Neston
Holywell
Coal field
Burton
Estuary of the River Dee
Flint
Chester & Holyhead Railway
Northop
Hawarden
CHESTER
Broughton
Mold
Chester & Mold Railway
Hope
R. Alyn
Gresford
Minera
Great Bala Fault
Berse
Railway

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remarkable of which is the "Great Minera vein," coinciding with a line of fault traversing the Denbighshire coal-field from south-east to north-west.

The coal-fields here described form part of the counties of Denbigh and Flint; and north of the valley of the Alyn become separated into two portions, by the upheaval along the line of a great fault of the Lower Carboniferous Rocks.* The tract south of this fault is called the "Denbighshire coal-field"; that to the north, the "Flintshire coal-field"—each of which will now be described separately.

DENBIGHSHIRE COAL-FIELD.

This coal-field commences about 3 miles south of Oswestry, where the New Red Sandstone begins to rest directly on the Millstone Grit, and extends northward by Oswestry, Ruabon, and Wrexham, to the north of the valley of the Alyn, which winds through a deep defile, and exposes in its banks an almost complete section of the coal-formation. The length of the coal-field is about 18 miles; and it is about 4 miles in breadth at Wrexham, where crossed by the section. (Fig. 9, p. 101.)

The general succession of the strata is as follows:—

		Thickness. Feet.
1. Trias, or New Red Sandstone		1,200
2. Lower Permian Rocks (thinning northwards) ...		1,000 to 2,000
3. Coal-measures	1. Upper Series, 1,000 feet. 2. Middle (with coals) 800 feet. 3. (Lower thin coals), 1,000 feet.	2,800 ,, 3,000
4. Millstone Grit and Yoredale Beds		800 ,, 1,000
5. Carboniferous Limestone		1,000 ,, 1,500

* This is one of the largest faults in Britain, and has been traced from the sea on the coast of Merionethshire, through Bala Lake, into Cheshire. See Maps of Geological Survey, Sheet 74, N.E. and S.W.

The Lower Permian strata consist of red and purple marls and sandstones, sometimes calcareous, and may be seen along the banks of the Dee west of Overton, and in the brook which flows eastward of Wrexham.

The coal-measures may be classed under three divisions. The upper, consisting of red and grey sandstones and reddish clays, and containing only a few very thin and worthless coals: of these beds there are good sections along the banks of the Alyn, west of Cresford. The middle series constitutes the coal-bearing strata, and contains the following coal-seams of good quality, besides several others not worth mentioning: this series corresponds, with slight variation, to that in Flintshire:—

*Succession of Coal-seams, Denbighshire Coal-field.**

	Yds.	Ft.	In.
1. *Top Sulphurous Coal* (not worked)	0	4	0
Strata	70	0	10
2. *Bottom Sulphurous Coal* (not worked)... ...	0	4	6
Strata	10	0	7
3. *Smith's Coal*	0	2	2
Strata	12	1	1
4. *Drowsall Coal* (good quality)	0	3	0
Strata	9	0	8
5. *Powell Coal*	0	3	3
Strata	9	1	3
6. *Two-Yard Coal*	0	6	0
Strata	11	0	0
7. *Crank Coal*	0	2	8
Strata, with Brassy Ironstone	10	2	6
8. *Brassy Coal*	0	5	0
Strata, with Black-Band Ironstone, 18 inches...	10	0	11
9. *Main Coal*, with a parting of clay, 15 ,, ...	0	7	5
Total	156	0	10

* This section was furnished to me by Mr. Napier, Manager of Westminster Colliery, 1859.

The lower measures contain several coal-seams, varying in thickness from 2 to 3 feet, which have been but little sought after in the presence of the thick seams from the middle series.

There are several valuable beds of iron stone, the principal being "the brassy" and "black-band" seams.

The remains of fish are abundant in this coal-field, and have been classed by the late Sir P. Egerton under the following genera: *Rhizodus*, *Cœlacanthus*, *Platysomus*, and *Palæoniscus*. The black-band ironstone is very full of fish-scales, teeth, etc., and also contains a bivalve shell of the genus *Anthracosia*. In the Lower Coal-measures the black shales contain *Goniatites* and *Aviculo-pecten*, as is the case in Lancashire and Yorkshire.

Though the coal seams are of good quality and thickness, and advantageously placed for working on a large scale, it is only within the last few years that these great resources have become recognised. In 1857 there were no very deep collieries; one of the deepest, Westminster Colliery, from which the section of the strata has been taken, being only 173 yards. Since that time several very deep shafts have been sunk, one of these, at Hafod, near Ruabon, belonging to the Ruabon Coal Company, descending to a depth of over

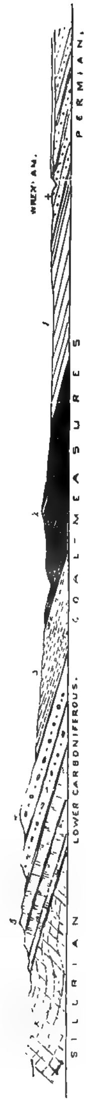

Fig. 9.—SECTION ACROSS THE DENBIGHSHIRE COAL-FIELD.
Length about 6 miles.

1. Upper Coal-measures without coal. 2. Middle Coal-measures with coal. 3. Lower Coal-measures with thin coals. 4. Millstone Grit. 5. Carboniferous Limestone.

500 yards.* According to the report on this coal-field (1904), the workings towards the east have been limited by a downthrow fault which passes near Wrexham.

The production of this coal-field has also greatly increased within the last few years, especially since the opening of the Great Western Railway, which carries the coal direct to the London market. Probably 500,000 tons are transported by this railway alone. In 1858, the quantity of coal raised in the Denbighshire coal-field amounted to only 527,000 tons; in 1903 it reached 2,612,380 tons.†

Resources in 1903.

1. Area of the coal-field	47 square miles.
2. Greatest thickness of coal-measures	3,00 feet.
3. Number of workable coal-seams from 2 feet and upwards, seven, giving a thickness of	30 feet of coal.
4. Quantity of coal unwrought, and likely to be clear for working to a depth of 4,000 feet	965,099,817 tons.‡

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* This colliery I had an opportunity of visiting soon after the first shaft had successfully won the Main Coal in 1868 or 1869.

† In 1869 the quantity was 1,427,701 tons. ("Mineral Statistics," 1869, p. 129.) In the returns for 1878, the output from all the North Wales collieries amounted to 2,222,257 tons.

‡ The estimate of Mr. Dickinson (1871) was 1,287 millions of tons. ("Report Coal-Commission," vol. i, p. 18.) My own estimate, as given in the 2nd edit. of this work, was 490 millions of tons to a depth of 2,000 feet, and half as much more to a depth of 4,000 feet.

CHAPTER VIII.

FLINTSHIRE COAL-FIELD.

THIS coal-field is disconnected from that of Denbighshire by the uprise of Carboniferous Limestone and Millstone Grit over a small tract between Gresford and Hope. From this it extends along the western side of the estuary of the Dee to Point of Aire, a distance of 15 miles; but throughout a considerable part of its range the productive portion is very narrow, and greatly broken by faults.

The general dip of the beds is towards the north-east, and there is no doubt but that they underlie the New Red Sandstone of the Cheshire plain; for they actually reappear on the Cheshire coast at Parkgate, where they are upheaved along a line of fault.*

The following is the general section of this coal-field :—

	Ft.	In.
1. *Four-Foot Coal* {Coal, Cannel}	4	0
Strata	41	0
2. *Bind Coal*	2	6
Strata, with ironstone	62	0
3. { *Hollin Coal* (in three beds)	6	6
Cannel...	1	6
Strata, with ironstone	29	0

* Map of the Geol. Survey, 79, N.E. Also Section Sheet 43, with description. For much information regarding this coal-field I am indebted to the late Mr. Beckett, of Wolverhampton, and to Mr. P. Higson, of Manchester.

		Ft.	In.
4.	*Brassy Coal*	3	0
	Strata	82	0
5.	*Main Coal*	7	0
	Strata ... ... 180 ft. to	300	0
6.	*Lower Four-Foot Coal* (in some places, *Cannel*) ...	4	0

It will be observed that the *Main* and *Brassy* coals of Flintshire and Denbighshire correspond with each other; that the "Hollin" coal of the former is the "Two-yard" coal of the latter, while the "Powell" coal represents the "Bind" coal. The intermediate ironstone-measures also correspond with those of Denbighshire.

The lower Four-foot coal is considered to be the same as the cannel seam of Leeswood, near Mold. It is exceedingly valuable, owing to the large quantity of oil which it yields on distillation; and it is said to yield a larger quantity of gas than the celebrated Wigan cannel.* Its position is about 100 yards underneath the Main coal, and its character as cannel (or gas coal) is considered to be limited to a comparatively small area.† The following is the section of the strata accompanying this seam :—

	Yds.	Ft.	In.
Black Shale	3	2	8
Light Shale	0	0	7
Black Bass	0	0	7
Top Cannel ... ... 2 ft. to	0	2	2
Curley Cannel ... ... 1 ft. 6 in. to	0	1	8
Bad Cannel	0	1	5
Black Shale	0	3	0

* According to the assay of Dr. Andrew Fyfe, the proportions are as follows: Wigan Cannel, 12,010 cubic feet per ton; Leeswood Curley Cannel, 14,280; and Leeswood Smooth Cannel, 9,972. Of course these proportions are liable to variation.

† In 1878, the quantity of oil-shale raised in Flintshire was 8,653 tons ("Min. Stat.," 1878, p. 148).

The following is a condensed section of the formation taken at Mold, Flintshire :—*

	Yds.	Ft.	In.	Yds.	Ft.	In.
Strata from surface	48	1	6	48	1	6
Hollin Coal	2	0	2	50	1	8
Brassy Coal	1	0	0	71	1	8
Rough Coal	1	0	0	88	2	2
Main Coal	3	2	0	103	1	2
Coal	1	0	0	107	1	2
Coal	1	1	0	113	2	2
Strata, with several seams of ironstone...	20	2	0	134	1	2
Coal	1	1	0	135	2	9
Coal	1	2	0	151	1	9
Shale	1	2	0	153	2	9
Coal { Coal 2 0 Bass 0 10 Coal 2 6 }	1	2	4	155	0	1
Coal	0	2	0	179	2	1
Cannel Coal	1	0	6	196	0	7
Oil Shale, 15 ins.; Black-Band Ironstone, 6 ins.	0	1	9	196	2	4
Wall and Bench Coal { Coal 0 1 0 Shale 0 0 6 Coal 0 1 4 } ...	0	2	10	219	2	6

In the Lower Coal-measures, below all the strata abovenamed, the late Mr. Binney informed me that there are several thin seams with roofs of black shale, containing *Goniatites* and *Aviculo-pecten*, corresponding to the Gannister coals of Lancashire and Yorkshire. These coals are visible in a brook section south of Hope, which in another part displays very beautifully the uncomformable superposition of the New Red Sandstone on the Lower Coal-measures.

The strata of the Flintshire coal-field rarely attain a

* For which I am indebted to the late Mr. H. Beckett, F.G.S.

great depth. If we cross the centre of the district from west to east, we find the beds repeatedly upheaved along dislocations ranging north and south. The result is, that the greater portion of the coal being placed so near the surface has already been exhausted, and probably not more than one-half remains for future use. The valley of the Dee seems to offer favourable positions for deep shafts, and already the coal is being won under high-water mark on Mostyn Bank. Mr. Strahan states that, by the Sea-lands borings, a fault was proved in a north-easterly direction from Sandycroft.*

There can scarcely remain a reasonable doubt of the continuation of the coal-formation from Flintshire to Lancashire and Cheshire under the intervening tract of the New Red Sanstone. The Promontory of Wirral, lying between the estuaries of the Dee and the Mersey, may be regarded with little hesitation as a coal-field concealed by New Red Sandstone, in which the depth will be found to depend on the thickness of that formation, the structure of which has been worked out with much care by the Geological Surveyors.† Coal has actually been proved on the east side of the river Dee north of Chester, as well as at Neston; and the late Mr. Woodhouse successfully carried down a shaft into the coal-seams at some distance from the shore opposite Bagillt, near Flint.

* Rep. Coal-Commission (1904).

† This is also the view of the Coal Commissioners, as expressed by Prof. Ramsay.—"Report," vol. i, p. 127 (1871).

Resources in 1903.

1. Area of coal-field	35 square miles.
2. Number of coal-seams at least six, giving a thickness of	35 feet of coal.
3. Unwrought and available quantity of coal (including the tract along the estuary of the Dee, and the coal-field of Neston, in Cheshire)	771 millions of tons.

The quantity of coal raised in 1878 was 707,785 tons, from 51 collieries, and in 1903, 571,756 tons; so that the production is stationary or on the decline. The quantity of coal in the actual and visible coal-field can scarcely last more than half a century; but there may be large supplies lying below the New Red Sandstone in the direction of the dip of the strata, and the borders of Cheshire.

N.W. S.E.

Fig. 10.—SECTION ACROSS THE ANGLESEA COAL-FIELD.
(Reduced from Section of the Geological Survey.)

CHAPTER IX.

ANGLESEA COAL-FIELD.

CROSSING a mountainous region of 45 miles in breadth from the Flintshire coal-field to the centre of Anglesea we find a series of Carboniferous strata, on the whole, similar to those just described.

The Anglesea coal-field forms a band of country stretching from Hirdre-faig to Malldraeth Bay, a distance of nine miles. Its breadth at Malldraeth Marsh is a mile and a half. The coal-measures are overlain unconformably by red sandstone, conglomerate, and marl, of Permian age; and from beneath the coal-strata the Millstone Grit and Carboniferous Limestone rise in succession, their base resting on highly-contorted and metamorphic schists of Cambrian or Lower Silurian age. The existence of this coal-tract is entirely due to an enormous fault, having at one point a down-throw on the north-west of 2,300 feet. On approaching this fault the coal-seams rise towards the south-east at a high angle; and through its agency the Carboniferous strata have been relatively lowered, and are

protected on all sides by the ancient Silurian rocks. (See Section, Fig. 10, page 108.)

The following is the general succession of the strata as determined by Prof. Ramsay: —*

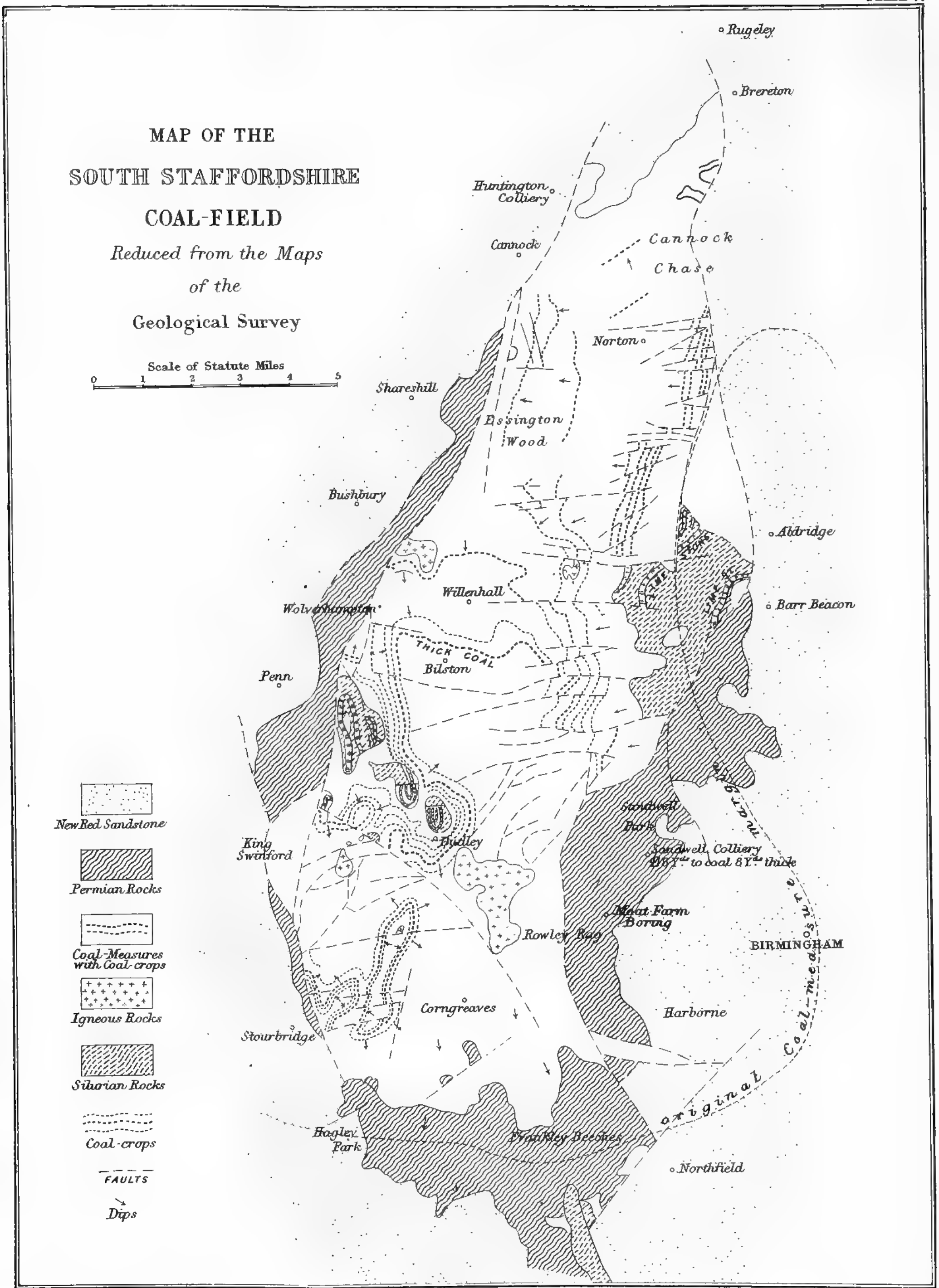
Succession of Strata, Anglesea Coal-field.

		Ft.	In.
Permian Rocks—	Red Sandstone, marl, and conglomerate ...	195	0
Coal-measures—	*Coal* ("Glopux") lying in lumps	9	0
1,309 feet.	Shale	51	0
	Coal	3	0
	Shale	63	0
	Coal	4	0
	Strata	75	0
	Coal (irregular)...	2	0
	Strata	43	0
	Coal	6	0
	Strata	90	0
	Coal (with cannel roof)	1	8
	Strata (about)	300	0
	Coal (supposed Berw Uchaf Coal, in three beds, with partings)	7	6
	Strata	650	0
Millstone Grit—	*Coal* (perhaps in Millstone Grit) ... 2 feet to	3	0
	Yellow Sandstone and conglomerate... ...	200	0
Carboniferous Limestone.	Gray and Black Limestone and Sandstone, with *Productus*, *Spirifer*, Corals, etc. ...	450	0

Some of these coal-seams crop up against the base of the Permian strata, proving the great discordance between the formations. A greenstone dyke rises in a line of fault near Berw colliery, but appears not to enter the Permian strata.

* Descriptive explanation of Section of the Geological Survey, Sheet 40; also Geological Map, Sheet 78.

Mr. Dickinson estimated that there were 5,000,000 tons of available coal remaining in this coal-field, worked by two or three little collieries, which in 1878 produced 672 tons, but at the present time coal-mining has apparently ceased.



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CHAPTER X.

SOUTH STAFFORDSHIRE COAL-FIELD.

THIS coal-field extends from the Clent Hills on the south to Brereton, near Rugeley, on the north, a distance of 21 miles, and is of an average breadth of seven miles. It appears to have been upheaved bodily along two great lines of fracture, which range in approximately parallel directions from north to south. Beyond these lines, Permian and Triassic rocks set in.*

Aspect of the Coal-field.—This district has been one of extreme productiveness in coal and iron ; and its proximity to the towns of Wolverhampton, Dudley, and Birmingham has imparted an extraordinary impetus to these centres of industrial pursuits. But, indeed, it may be said that the whole line of country connecting these towns, a distance of 12 miles, forms one great workshop ; and on a fine night, the spectacle from the walls of Dudley Castle, which

* The earliest description of this coal-field appears to have been that of Mr. Kier, the friend of Whitehurst, who produced an able memoir on the coal, limestone, and trap-rocks of South Staffordshire, published in "Shaw's History" of that county, towards the end of the eighteenth century. The Dudley and Midland Geological Society is doing useful work in collecting data, and noting fresh openings in the strata, with a view to a possible new survey on the larger scale of 6 inches to 1 mile which has been carried out in the northern coal-fields.

Note.—The section at the side of p. 112 is reduced from one by Mr. Jukes.

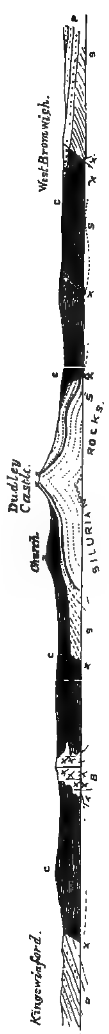


Fig. 11.—SECTION ACROSS THE SOUTH STAFFORDSHIRE COAL-FIELD.
Distance about 6 miles.

WEST. EAST.

P. Permian Rocks. C. Coal-measures. S. Upper Silurian Rocks. B. Basalt. × Faults.

rises from the centre of the coal-field, is one which has scarcely a parallel. The whole country within a radius of five or six miles is seen to be overspread by collieries, iron-foundries, blast-furnaces, factories, and the dwellings of a dense population; and, from amidst the thick smoky atmosphere, the tongues of fire from the furnaces shoot up an intermittent light which illuminates the whole heavens. But the spectacle before our eyes does not represent the whole sum of human labour; for whilst 10,000 hands are at work above ground, one-half as many, perhaps, are beneath the surface, hewing out the coal which is to be the prime mover of the whole machinery in motion above ground.

Physical Geology.—It has been shown by the late Prof. Jukes,* that while the Lower Carboniferous rocks were being deposited over other parts of England, a band of country stretching from Shropshire across South Staffordshire and Warwickshire was dry land. Consequently there is no Carboniferous Limestone or Millstone Grit in South Staffordshire; and the coal-measures repose directly on an eroded surface of Upper

* "South Staffordshire Coal-field," "Mem. Geol. Survey," 2nd edit. (Preface). See Geol. Maps, 62 S.W., 62 N.W., and corresponding sections.

Silurian rocks, which, at Sedgley, Dudley, and Walsall, rise from beneath the coal-formation in a series of isolated hills. These bosses of Silurian rocks indicate the proximity of that ridge of land which formed the original limit towards the south of the coal-formation of central England, and is now known to stretch beneath the Permian formation under the Clent Hills in an east and west direction. This ridge was reached in shafts sunk, by the Messrs. Dawes at Wassel Grove and Manor Farm, in search of the thick coal; it having been assumed that the coal-beds to the north of Hales Owen would be found to extend southwards beneath the Permian Rocks. No seams, however, of any importance were found in the shafts; but at some distance down, fragments of carbonized plants mixed with sandstone, gravel, and pieces of Silurian rocks were encountered, mingled with fragments of Carboniferous plants. Below these the Upper Silurian rocks were pierced for some depth.* These phenomena, so discouraging to the enterprising proprietors, yet so full of interest to the physical geologist, arc capable of explanation on the supposition that the shelving shore, or margin, of the Carboniferous area formed of Silurian rocks, was here reached. Another ridge of Silurian rocks has been found beneath the Permian strata along the eastern margin of the coal-field, and was first described by Sir R. Murchison.†

* Ramsay, "Coal-Commission Report" (1871), vol. i, p. 120. An account of these trials was given by Mr. Henry Johnson, at a meeting of the "Mine Agents' Association," held in Dudley, in 1868. The cost of the two experiments was about £25,000.

† "Silurian System." The late Mr. H. Beckett, F.G.S., informed me, however, that at their new colliery, at Hales Owen Abbey, the Messrs. Dawes have proved the "Thick Coal," though not of its full thickness.

But while trials for coal in a southerly direction towards the Clent Hills have been so unfruitful, others in an easterly direction have been attended with success. In the neighbourhood of Birmingham, the "thick-coal" has been reached (1876), in the shafts of the Sandwell Colliery Company, after persevering efforts, under the direction of Mr. Henry Johnson, though sometimes attended with discouraging appearances.

After passing through about 110 yards of Permian beds, the coal-measures with plant-remains were met with, and ultimately "the thick-coal," 8 yards in thickness and of good quality, was reached at a depth of 418 yards. At Baggeridge Wood, outside the western boundary fault, the "thick coal series" was proved by boring in 1901 nearly a mile outside the visible coal-field, and shafts are now being sunk to develop this new area. Borings are also being put down at Moat Farm, below the Permian beds at Smethwick. In 1880, the thick coal (24 feet in thickness) was sunk through at Hamstead at a depth of 612 yards, about 1 mile north of Sandwell; and productive measures have been proved at Langley, to the south of the same place.*

Succession of Formations and Coal-series.

The general succession of the strata, as given by Mr. Jukes, is as follows:—

* For much valuable information regarding the recent extension of mining operations in South Staffordshire, the reader is referred to the statement of Prof. Lapworth and Mr. Sopwith, in the Report of the Coal-Commission of 1904.

		Ft.
Trias—Bunter Sandstone, 1,200	1. Upper mottled Sandstone ...	500
	2. Conglomerate beds	500
	3. Lower mottled Sandstone ...	200
		1,200
Permian [Lower Division], 1,000 to 3,000	1. Breccia of felstone, porphyry, and Silurian Rocks. 2. Red marls, sandstone, and calcareous conglomerate.	1,000 to 3,000

Coal-measures—Southern District.

		Ft.
Upper Coal-measures—1,300	Red and mottled clays, red and grey sandstone, and gravel beds	800
Middle Coal-measures—510	1. *Brooch coal*	4
	Strata, with ironstone	130
	2. *Thick coal*	24 to 30
	Strata, with "Gubbin Ironstone" ...	20
	3. *Heathen coal*	4
	Strata, with ironstone	109
	4. *New mine coal*	8
	Strata, with ironstone	16
	5. *Fire-clay coal*	7
	Strata	30
	6. *Bottom coal*	12
	Strata, with several courses of ironstone	140
Upper Silurian Rocks	1. Ludlow Rocks, with Aymestry Limestone.	
	2. Wenlock and Dudley Limestone and Shales.	
	3. Woolhope Limestone (?).	
	4. Llandovery Sandstone.	

Coal-seams.—From the above list it will be seen, that in the Dudley district there are six workable seams of coal, giving a total thickness of 65 feet. The most remarkable of these is the "Ten-yard," or "Thick coal," of a general thickness of 30 feet, and a source of enormous wealth to

the district. It underlies a large area, at a moderate depth; and has either been worked out, drowned, or destroyed to such an extent, that probably little more than one-tenth remains to be won.* It is rather subject to "rock-faults," or "horse-backs," instances of which are given by Mr. Jukes;† one of which the author had an opportunity of examining at Baremoor colliery, where the whole mass of coal has been replaced by sandstone—the junction being formed of a series of interlacings of sandstone and coal.

Thinning of the Strata southwards.—In the northern part of the coal-field, at Essington and Pelsall, the Thick coal of Dudley becomes split up into nine distinct seams, with a combined thickness of exactly 30 feet of coal; but separated by 420 feet of sandstones and shales, all of which are absent to the south of the "Great Bentley fault." This remarkable thinning out of the strata takes place in a distance of five miles from north to south, and is an additional instance of the higher amount of persistency in the thickness of the coal-seams than in that of the sedimentary strata with which they are associated.

Dip of the Beds.—North of the Great Bentley fault, the general dip is from east to west; and there is an extensive tract of about ten miles in length extending to Beaudesert, and three in breadth, over which the lower coal-seams lie nearly undisturbed, as those which are worked at Essington and Wyrley occupy a higher position. At Brereton there are several shafts sunk through conglomerate of the New

* It is to be hoped that, as the value of the coal increases, the colliery proprietors may be induced to combine together to unwater the large tracts now flooded near Dudley; as it is only by such united action that this desirable end can be accomplished.

† *Supra cit.*, p. 112.

Red Sandstone formation under which coal is extensively worked.

Cannock Chase.—Extensive mining operations have recently been commenced over the northern portion of Cannock Chase, which is partly formed of New Red Conglomerate, and undoubtedly conceals an extensive coal-field. A pair of shafts have recently been sunk in the Huntington Valley to the "Deep coal," which was reached at 299 yards from the surface, all the shallower coals having been found in their usual positions.* One of the proprietors, Mr. M'Ghie, has favoured me with the following section of these pits, for insertion here :—

Name of Seam of any Thickness.			Depth from Surface.		
	Ft.	In.	Yds.	Ft.	In.
Coal	2	4	27	1	3
Cannock Brooch Coal	3	11	36	0	2
Five-feet coal (8 inches, parting included)	5	11	75	1	9
Coal	3	6	88	2	3
Old Park Coal	5	0	124	0	2
Coal	4	2	178	0	5
Coal	2	1	205	1	0
Coal	2	3	208	1	2
Yard Coal	3	2	220	2	0
Bass Coal	4	2	243	0	3
Cinder Coal	3	10	265	1	3
Shallow Coal	9	3	271	1	8
Coal	2	2	280	2	3
Deep Coal	4	4	299	1	2

Coals under 2 feet in thickness omitted.

Another shaft has been sunk in the same neighbourhood

* From a communication from the late Mr. H. Beckett, dated 29th April, 1871. The new colliery belongs to the Cannock and Rugeley Colliery Company.

into the Coal-measures by the Huntington Colliery Company, which after passing through 354 feet of New Red Sandstone and conglomerate, entered the coal-measures and passed through several seams of coal, one of which is 5 feet in thickness. They are considered by Mr. F. W. North, who has furnished the author with the particulars, as the representative of the Upper Wyrley series of coal-seams.

IGNEOUS ROCKS, CONTEMPORANEOUS AND ERUPTIVE.

Basalt.—In several localities over the southern portion of the coal-field, varieties of igneous rocks are found, frequently burrowing through and altering the coal-measures, and sometimes resting upon them. The finest exhibition is the basaltic mass of Rowley Regis, or "Rowley rag," forming a hill about two miles in length, and 820 feet in height. This basalt assumes the columnar structure, affording examples of prisms as perfect as those from the Giant's Causeway in Ireland. Mr. Jukes considered that this rock has been poured out in the form of a lava-flow, during the coal-period; for the beds of coal dip under the basalt, and have been followed till found "blackened," or charred, and utterly worthless.*

At Pouk Hill, near Walsall, is another mass of columnar basalt, in which there are vertical, horizonal, bent, and radiating columns.†

* "South Staffordshire Coal-field," etc., p. 120.

† The researches of Mr. S. Allport on the microscopic structure of the various trap rocks of South Staffordshire, Worcestershire, and Coalville in Leicestershire, which penetrate the coal-measures, tend to show that these have nearly the same composition, viz., triclinic felspar (probably Labradorite), augite, titano ferrite, or magnetite, and olivine, as essentials, with occasionally apatite and chlorite, calc spar, and zeolites, the latter being of secondary

Basalt or Melaphyre.—In the Lower Coal-measures, a sheet of melaphyre spreads almost without interruption from the base of Rowley Regis, through the centre of the district, to Wolverhampton, Bilston, and Bentley. This would appear to have been a lava-flow of earlier date than the basalt, but ejected from the same vent, which we may suppose to be situated near the centre of the hill. There are also beds of volcanic ashes and gravel associated with the Upper Coal-measures at Hales Owen, probably nearly contemporaneous in their formation with the Rowley basalt.

Ironstones.—The ironstones occur in beds, associated with shale, and are the principal repositories of the fossils. The principal bands are—

1. The Pins and Pennyearth Ironstone-measures.
2. The Grains Ironstone } Below the Thick Coal.
3. The Gubbin Ironstone }
4. The New Mine Ironstone.
5. The Pennystone Ironstone, with marine fossils, *Productus*, *Aviculopecten*, *Lingula*, etc., a *Palechinus*, and fish-teeth and bones.
6. Poor Robin, and White Ironstone—only local.
7. Gubbin and Balls Ironstone.
8. Blue Flats, Silver Threads, and Diamond Ironstone.

Fossils.—Fish: *Gyracanthus formosus* (ichthyodorulites), *Rhizodus*, *Pleurodus*, *Ctenoptychius*, *Megalichthys Hibberti*, *Cochliodus*, *Pœcilodus*. Molluscs: *Productus*, *Conularia*, *Lingula*, *Myalina*, *Anthracosia acuta* (in coal), *Aviculopecten scalaris*, in the Lower Measures; Annelides; and the usual Coal-measure plants.*

formation; hence these rocks would fall under the name of "Melaphyres." See Mr. Allport's paper "On the Basaltic Rocks of the Midland Coal-fields," "Geol. Mag.," vol. vii, p. 159 (1870).

* These fossils were determined by the late Mr. Salter, of the Museum of Practical Geology. They are similar to those of the "Pennystone" band of Coalbrook Dale.

Resources.

In order to arrive at an estimate of the resources of this coal-field, it has been necessary to consider the northern and southern halves separately; as the former contains about three-fourths of the original quantity of coal, the latter only one-tenth.

1. Area of coal-field	93 square miles.
2. Average thickness of workable coal above 2 feet	50 feet.
3. Total estimated quantity of coal remaining unworked	1,953,277,000 tons.
4. Total estimated deductions due to all causes (barriers, faults, etc.) being 27·5 per cent. ...	538,179,000 "
5. Available quantity remaining unworked ...	1,415,098,000 "

Mr. Hartley's estimates* included in one sum the available quantity of coal from the South Staffordshire and Shropshire coal-fields, giving a total of 1,906,119,768 tons, of which about 20 millions of tons belonged to the latter. This would have left about 1,886 millions for South Staffordshire, now reduced by the annual output to the above figure. Both estimates would thus appear to be very close approximations.

In the year 1903, there were raised in the two coal-fields of Staffordshire 13,037,439 tons of coal.

* Report, "Commission," 1871.

CHAPTER XI.

NORTH STAFFORDSHIRE COAL-FIELD.

THE North Staffordshire coal-field, though of smaller area than that of South Staffordshire, has vastly greater resources. The strata are about four times as thick, with twice the thickness of workable coal; and instead of being bounded on either side by downthrow faults which at one step place the coal at unusual depths, the coal-measures of North Staffordshire dip under the Permian and Triassic rocks along a line of many miles at the south-western border of the coal-field, and under these formations coal may be obtained at a future day. Moreover, there are none of those protrusions of igneous rocks which have produced so much injury to the coal-beds near Wolverhampton, Dudley, and Hales Owen. This coal-field is in shape that of a triangle, with its apex to the north at the base of Congleton Edge; the eastern side is formed of Millstone Grit, and the western of New Red Sandstone or Permian strata, which are brought down along the line of a large fault. Along the south the coal-measures are overlaid by Permian marls and sandstones, and these strata run far up into the heart of the coal-field by Newcastle, along the line of a great fault, which ranges N.N.W. towards Talk-on-the-Hill.*

* Map of the Geological Survey, Sheets 72, N.W., and 73, N.E.

Structure of the Coal-field.—On referring to the map, it will be observed that along the northern and central portions the strata have been thrown into a double fold along synclinal and anticlinal axes, which appear to converge towards the apex of the coal-field at Congleton Edge; and in the opposite direction to diverge, till at the southern margin they are several miles apart. The synclinal axis is a prolongation of the Biddulph Trough, and ranges due south towards Newcastle-under-Lyne, in which direction it gradually flattens out, and further south disappears. The anticlinal (or saddle) stretches towards the S.S.W. from Mowcop, causing a rather sharp reversal of the dip through Silverdale, and disappearing amongst the Permian and Triassic strata between Madeley and Keel. Along either side of this axis the Upper Coal-seams rise, and crop out, for two or three miles in nearly parallel lines; these ultimately disappear under higher strata in the valley west of Keel.

Fig. 12.—GENERAL SECTION ACROSS THE NORTH STAFFORDSHIRE COAL-FIELD. (*Southern portion*).

SOUTH-WEST. NORTH-EAST.

1. New Red Conglomerate.
2. Permian rocks.
3. Upper Coal-measures.
4. Middle ditto, with Coal.
5. Lower Coal-measures, with thin Coals.
6. Millstone Grit.

Faults.—With a few exceptional tracts, this coal-field is remarkably clear from faults; there are, however, several large lines of fracture, which have an important influence on the structure of the district. To the west of Mowcop, where the Millstone Grit emerges from beneath the coal-measures, the coal-field is bounded

by the prolongation of the "Red-rock fault" of Cheshire, which produces a downthrow to the N.W. of the New Red Sandstone. This fault extends along the western base of Congleton Edge, and opposite the town of Congleton brings the Carboniferous Limestone and New Red Marl nearly into contact. Another fault of importance passes in a north-westerly direction by Newcastle and east of Hanchurch, and throws down the beds on the east to the extent of about 350 yards; a third and parallel line passing by Hanford has a downthrow of 200 yards on the same side. East of Longton, the coal-field is bounded by a large fault, which was visible at the entrance to the railway tunnel when in course of construction; on the east side of it the New Red Sandstone is introduced.

Permian Beds.—These beds consist of purple and brownish-red sandstones, sometimes calcareous and mottled, interstratified with thick beds of red marl. They occupy a position intermediate between the coal-measures and the New Red Sandstone, and are unconformable to both. Their unconformity to the coal-measures is proved by the fact, that they rest indiscriminately on different portions of the formation in different localities. Thus we find them north of Madeley resting on strata of the coal-measures about the position of the "Red Shag" ironstone; while east of Newcastle, and near Stoke-on-Trent, they rest upon beds several hundred feet above this well-known band. The Permian beds attain their greatest development of 500 to 700 feet south of Newcastle-under-Lyne.

The unconformity of the New Red Sandstone to both the Permian and Carboniferous rocks is proved by even more striking cases of overlap than that above described; thus, while near Trentham we find several hundred feet of

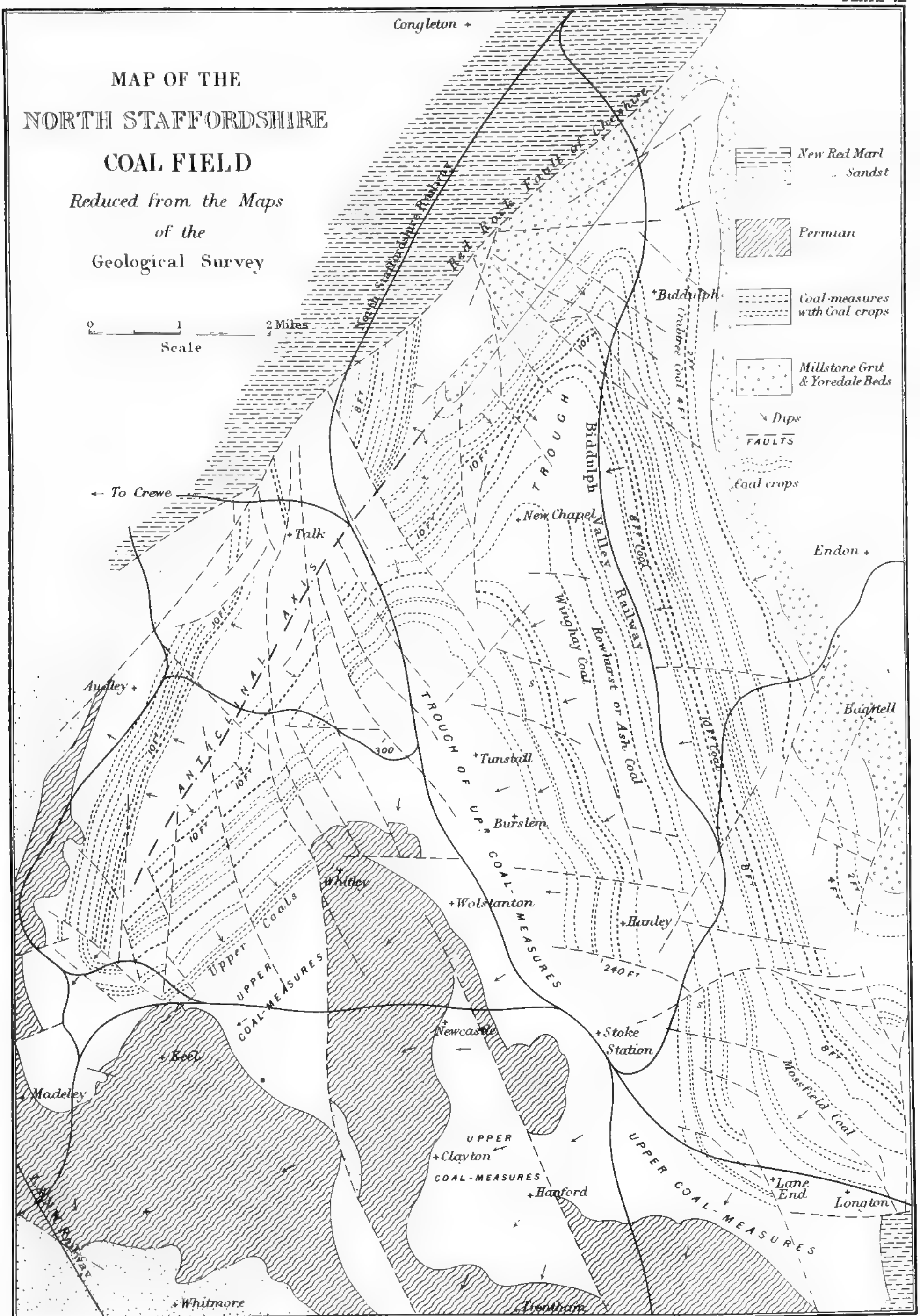
Permian beds intervening between the New Red Conglomerate and the coal-measures, south of Longton the former formation rests directly on the coal-measures themselves.

*Succession of Strata, North Staffordshire Coal-field.**

			Greatest Thickness. Ft.
Permian		*Rocks*—Red and purple sandstones, marls, and cornstones (with plants), strata slightly unconformable to the coal-measures	600
Coal-measures—5,000 feet.	1.	*Upper*—Brown sandstones, greenish conglomerate (like the volcanic ashes of S. Staffordshire), with thick beds of red and purple mottled clays; thin coals, and a bed of *Spirorbis* Limestone at Fenton†	1,000
	2.	*Middle*—Sandstones, shales, with ironstone, and about 40 coal-seams	4,000
	3.	*Lower*—Black shales and flags, with Wetley Moor thin coals, and the red ironstone of the Churnet Valley. (*Goniatites*, *Pecten.*) ...	1,200

* See Horizontal Sections of the Geological Survey, Sheets 42 and 55, with Explanations. This coal-field was surveyed on the 1-inch scale by Sir W. W. Smyth, and the Author, in 1856–57. A full description of the coal-seams and iron-stones, with their analysis, has been published in "The Iron Ores of Great Britain," Part IV, "Mem. Geol. Survey." Recently, a fresh survey on the 6-inch scale has been carried out by Messrs. W. Gibson, G. Barrow, and C. H. Strangways, under the direction of Mr. J. J. H. Teall, F.R.S.

† This remarkably persistent band was discovered by Mr. Binney, F.R.S., and Mr. J. Ward, of Longton. Recently the Upper Coal-measures (in part) have been grouped by Mr. W. Gibson under the name of the "Keel Series,"



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	Greatest Thickness. Ft.
Millstone Grit—Coarse grits, shales and flags ...	1,000
Yoredale Rocks—Black shales, etc., with marine fossils	3,100
Carboniferous Limestone	4,000 to 5,000

If we compare the above section with that of South Staffordshire, we cannot but be struck by the vast accession of sedimentary materials exhibited by this coal-field as compared with the latter—an accession which, it should be observed, takes place in a northerly direction.

*Succession of Coal-seams and Ironstones.**

	Ft.	In.
Black-Band Ironstone (good quality) ...	1	6
Marl and bass (black shale)	36	0
Red Shag Ironstone (variable) ...	2 ft. to 4	0
Coal	1	9
Marl and bass	71	6
Red Mine Ironstone (good)	2	3
Coal	2	0
Marl and bass	35	9
Coal	1	8
Binds, coal, and bass	62	6
Coal	1	0
Rock, binds, and bass	77	0
Coal	0	9
Marl, warrant, and rock...	78	0

and he regards them as conformable to the Permian Beds, the apparent unconformity being explained by faulting. "Quart. Journ. Geol. Soc.," vol. lvii, 1901. Report by Messrs. Lapworth and Sopwith, Royal Coal-Commission (1904).

* A valuable communication on the qualities of the coal-seams in this coal-field will be found in the "Trans. Geol. Soc., Manchester," by Mr. C. Bradbury, 1861–62.

	Ft.	In.
Bassy Mine Ironstone (good)	4	0
Coal	2	0
Little Row Coal	2	2
Peacock Coal	5	8
Metal and binds (sandy shale)	40	6
Spencroft Coal	4	0
Warrant and metal (shale)	53	6
Grubbin Ironstone in shale	6	0
Binds	35	5
Great Row Coal	9	0
Binds, rock, and bass	78	9
Cannel Row Coal	6	6
Various strata	99	0
Wood Mine Coal	1	0
Pennystone Ironstone	2	0
Deep Mine ,, ...	0	10
Coal	3	0
Strata	69	0
Chalky Mine Ironstone	1	0
,, *Coal*	1	
Brown Mine Ironstone	0	8
Coal	1	0
Strata, with beds of ironstone	59	4
Bungilow Coal	3	1
Marl, binds, and rock	108	5
Coal	1	0
Strata, with *Bay Coal*	97	3
Winghay, or *Knowles Coal*	5	0
Metal and bass	35	6
Winghay Ironstone	1	5
Strata	115	8
Billy Mine Ironstone	0	6
Coal	1	6
Bind and bass	35	4
Coal	1	6
Rock, metal, and bind	34	6
Four-Foot Coal	2	9
Clay, bass, and metal	50	0
Ash, or *Rowhurst Coal* (house coal) ...	11	6
Marl, metal, etc.	81	3

	Ft.	In.
Burnwood Ironstone	1	0
Coal	5	3
Strata	54	0
Twist Coal and Cannel	3	6
Strata	59	0
Coal	1	6
Dark metal	97	0
Strata	292	7
Birchenwood Coal (house coal)	5	3
Strata	65	6
Mossfield, or *Easling Coal*	4	0
Dark metal	34	6
Coal	2	3
Strata	61	6
Coal	2	3
Strata	129	0
Yard Coal	3	6
Binds	31	0
Ragman Coal	4	6
Strata	79	0
Banburies { *Rough 7-Foot Coal* ...	4	3
Banburies { Strata	124	8
Banburies { *Stony 8-Foot Coal*	4	0
Strata	120	0
Ten-Foot Coal (strong coal)	5	9
Strata	131	0
Bowling-Alley Coal	4	6
Strata	81	0
Holly Lane Coal	5	10
Strata with *Hard Mine*	84	0
Sparrow Butts Coal	5	1
Strata	222	0
Flats Coal	2	8
Strata	108	0
Frog's Row Coal	4	2
Strata	30	0
Cockhead Coal	8	6
Strata	420	0
Bullhurst Coal	5	6
Strata	60	0
Winpenny Coal	3	0

Lower Coal-Measures.—These beds, occupying a band of country on the dip of the Millstone Grit, contain two seams worked at Wetley Moor, of a thickness of 4 feet and 3 feet respectively. Amongst these strata, which are often deeply stained with red iron-oxide, is the valuable band of iron-ore, worked in the Churnet Valley; the fossils are of marine genera.

Ironstones.—Several of the coal-seams are roofed by beds of valuable ironstone, so that both can be worked together; of these the "red shag," the "red mine," the "bassy mine," and the "deep mine," and "chalky mine" ironstones are amongst the most worthy of note. The occurrence of thick beds of excellent ironstone, forming the roof of the coal-seams, is one of the special features of this coal-field which greatly enhances its economic importance.

Fossil Remains.—Some of the beds in this coal-field are very rich in remains of fish, which have been collected with much perseverance by Messrs. Garner and Molyneux, and more recently by Mr. J. Ward, of Longton. Of these, a fine series was exhibited at the Meeting of the British Association at Manchester.* The following list, from the collection of Mr. Ward, has been kindly furnished by him, having had the benefit of revision by the late Sir P. Egerton, one of our highest authorities in ichthyology:—

FISH.—*Megalichthys Hibberti*, *Rhizodus* (three or four species), *Holoptychius*, *Rhizodus incurvus*, *Gyrolepis* (five or six species), *Palæoniscus*, *Cœlacanthus* (two species), *Platysomus parvulus*, *Pl.* (new species), *Acanthodus* (new species).

FISH-TEETH.—*Diplodus gibbosus*, *D.* (*Pleuracanthus*) *minutus*, *Hoı pacodus*

* "Trans. Brit. Assoc.," p. 103 (1859). Mr. Ward has since drawn up an account of the remarkable fossil fauna of this coal-field in a collected form from papers in the proceedings of the North Staffordshire Naturalists' Field Club (1877).

(*Ctenoptychius*) *apicalis*, *H. pectani*, *H. denticulatus*, *Helodus simplex*, *Acrodus*, *Diplopterus affinis*, *Cladodus*, *Petalodus*; also seven or eight of new, or indeterminate, species.

ICHTHYODORULITES.—Species of *Rhizodus Hibberti*, *Orthacanthus cylindricus* (18 inches long), *Gyracanthus formosus*, *G. tuberculatus*, *Pleuracanthus lævissimus*, *Ctenacanthus Hybodoides* (Egerton), *Leptacanthus*, *Ctenodus* (palate).

MOLLUSCS.—From a bed called the "Bay-coal bass," lying rather high up amongst the coal-series, the following have been obtained by Mr. Ward:—*Nautilus*, *Goniatites*, *Aviculo-pecten*, *Melania*, *Productus*, *Lingula*, *Discina*, and a few other forms. These are all marine genera, and indicate a temporary inroad of the sea-waters over this area. In the "Ten-foot" seam of Lord Granville's colliery at Hanley, there is a band of shale filled with the genera *Anthracoptera*, *Anthracomya*, and *Anthracosia*, together with *Goniatites Listeri*, *Aviculo-pecten papyraceus*, *Posidonia Gibsoni*, and *Spirorbis*. The association of the former-named genera with others of known marine habits has also been observed in Lancashire, and seems to show that all are alike marine, or at least estuarine. *Aviculo-pecten* and *Goniatites* have also been observed, by Mr. Binney, in the Lower Coal-measures of the Churnet Valley.

Resources.

There are few coal-fields in the United Kingdom which, in proportion to their extent, are so richly stored with minerals, and which, owing to the arrangement of the strata towards the south and west, give promise of such high productiveness in the future. That the resources of this district—till within the last 50 years not properly recognised,—are now coming into full play, is evinced by the rapid increase in the production of coal as well as of iron. In the two years extending through 1857–59 the production nearly doubled itself; and since that time it has increased by about three-fourths, while the number of collieries has not proportionably increased; showing the larger scale upon which the mines are now being worked. I give the estimate of the actual resources, as determined

by Prof. Lapworth and Mr. Arthur Sopwith, the members of the Royal Coal-Commission (1901) appointed to report upon this district.

1. Area of coal-field (exclusive of the Cheadle and Goldsitch basins)	75 square miles.
2. Total thickness of measures with coal	5,000 feet.
3. Number of workable coal-seams about 30, with a thickness of available coal amounting to ...	150 ,,
4. Total estimated quantity of coal remaining unworked	5,267,833,000 tons.
5. Estimated deductions due to pillars, faults, barriers, etc., being 17 per cent.	899,782,000 ,,
6. Estimated net available quantity remaining unworked for future use	4,368,050,000 ,,

The above estimates include the small outlying coal-basins of Cheadle and Wetley, containing about 95½ millions of tons. The resources of the North Staffordshire coal-field, returned by the late Mr. Elliot, amounted to 3,680 millions of tons available for future use.

Since the Report of the Commission of 1871, the coal-field has been extended both in depth and area. Prior to 1870 little coal was worked at great depths, but, at the present time, coal is being worked at depths over 2,000 feet. Thus, at Florence Colliery, the lowest seam now being worked is the Mossfield, at a depth of 2,775 feet, and has recently been sunk to at Fenton Colliery, at a depth of 2,553 feet.

CHAPTER XII.

CHEADLE COAL-FIELD, STAFFORDSHIRE.

THIS small, and slightly productive, coal-field stretches from the valley of the Churnet, on the north-east, to the hills of New Red Sandstone, which stretch in a picturesque semicircle along its southern borders. Towards this range the strata dip (S.S.W.), and on the north side of the Churnet the high moorlands of the Millstone Grit rise from beneath the coal-formation. In the centre of the coal-field, an outlier of New Red Conglomerate reposes unconformably on the Coal-measures, and forms the site of the pretty town of Cheadle.

The following is the succession of the coal-seams :—

1. Two-yard coal.
2. Half-yard coal.
3. Yard coal.
4. Littley coal.
5. Four-foot coal.
6. Woodhead 3-feet coal.

According to Mr. Elliot, this little coal-field contained in 1870 about 104,524,000 tons of coal available for future use.* In the estimate for the available coal of North Staffordshire (1904), that of Cheadle is included.

* "Report, Coal-Commission," vol. i, p. 27.

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Goldsitch Trough.—This is a narrow valley lying to the east of Wetley Rocks, composed of the red strata of the Lower Coal-measures, disposed in the form of a trough, with a north and south axis. It has a surface of area of 90 acres, and contains about 110,000 tons of coal.

Hæmatite Bed of Churnet Valley.

The Lower Coal-measures of the Churnet Valley contain two thin coals, one of which has a roof of black shale with *Goniatites* and *Aviculo-pecten.** Below these there occurs a valuable bed of iron ore, which has been extensively worked along the valley from the outcrop, and at Froghall. In thickness it varies from 6 to 20 inches, is of a deep red colour, and contains about 35 to 40 per cent. of iron. It is embedded in shale highly impregnated with hydrated peroxide of iron. The analysis of this ore by Dr. Angus Smith, from a good sample obtained by Mr. Binney, is as follows :—

Peroxide of iron	68·610
Silica	5·490
Carbonate of lime...	18·170
Carbonate of magnesia	3·723
Manganese, alumina, and moisture ...	4·007
	100·000

"*The Potteries.*"—Over that portion of the coal-field extending eastward of the Permian rocks of Newcastle are situated "The Potteries," a group of populous towns, the seat of that branch of industry originated by Wedgwood. From this all parts of the world are supplied with china-

* Mr. Binney, "Trans. Geol. Soc.," Manchester, vol. ii, p. 81.

ware rivalling that of Dresden; with vases and various kinds of vessels modelled after Etruscan patterns, but adorned with paintings from natural models, executed with a perfection of colouring and outline to which the Etruscans never attained; here also are produced those tesselated pavements which adorn so many of our churches and public buildings. For the production of these works of art chalk-flints are brought from the south of England, decomposing granite (china clay) from Cornwall, gypsum from Chellaston, siliceous chert from Derbyshire. The coarser kinds of earthenware, as also tiles, bricks, and pipes, are made in large quantites from the clays of the Upper Coal-measures, while the coal is at hand for heating the baking ovens, and calcining the wares. The appliances and materials necessary for the prosecution of fictile manufactures are here accessible or easily available, and have contributed to render this locality the metropolis of British ceramic art.

CHESHIRE COAL-FIELD.

This is a small tract of Middle and Lower Coal-measures, lying to the south of the Mersey, above Stockport. It is bounded along the west by Triassic and Permian rocks, which are brought in along the line of the "Red-rock fault of Cheshire." Including the tract formed of Lower Coal-measures, the southern termination of the coal-field is opposite Macclesfield; while the central portion lies east of Poynton, where there are extensive collieries. There are several valuable seams of coal, including the "Mill mine," 4½ feet thick; the "Sheepwash mine," the "Great mine," the "Four-feet mine," the "Silver

mine," the "New mine," and the "Redacre mine," which represents the Arley or Royley mine.* Mr. Dickinson estimated (1866) the available quantity of coal at 200 millions of tons.†

Resources of the Cheshire Coal-field.

The quantity remaining available by the Commissioners of 1904 is 291,831,271 tons, including a small area of Derbyshire, estimated to contain about 6,000,000 tons. The output of this coal-field is decreasing, having been 929,150 tons in 1870, and in 1903 it had fallen to 436,550 tons; but it is probable that there is a large quantity below the New Red Sandstone and lying to the west of "the Red Rock fault," which may be in reserve for future use; though owing to the thickness of the sandstone, which is doubtless charged with water, there may be much difficulty in putting down shafts.

* "Geology of Stockport, etc." "Mem. Geol. Survey," p. 29.
† "Report, Coal-Commission," vol. i.

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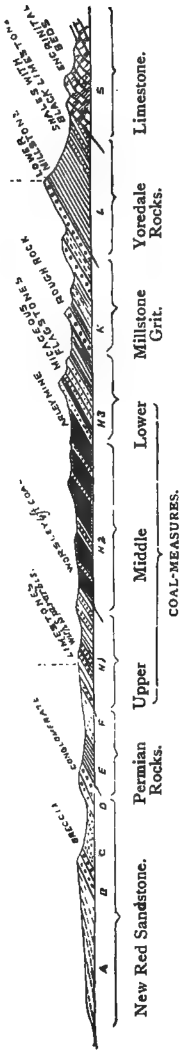
CHAPTER XIII.

SOUTH LANCASHIRE COAL-FIELD.

THIS great coal-bearing tract is very irregular in outline, and consequently difficult to describe. It may, however, be said to occupy a band of country lying east and west, sending offshoots at intervals into the Trias and Permian formations on the south, and into Lower Carboniferous strata which form its mountainous limits on the north. These offshoots are occasioned generally by enormous faults.

The extreme western boundary is a great fault, which, throwing down the New Red Sandstone on the west side, ranges through Eccleston, Lathom Park, Bickerstaffe, Knowsley Park, and Huyton. To the northward the high moorlands, formed of Millstone Grit and Lower Coal-measures, traversed by deep valleys with scarped flanks, reach elevations of 2,000 feet, and stretch with a semicircular outline from Chorley to Staleybridge, by Bolton,

Fig. 13.—GENERAL SECTION ACROSS THE CARBONIFEROUS ROCKS OF SOUTH LANCASHIRE.



Bury, Rochdale, and Oldham. From this elevated tract the country gradually descends towards the Valley of the Mersey, and the coal-measures dip under the Triassic and Permian strata, which form the low-lying districts, by Rainford, Newton, Ashton-in-Makerfield, Leigh, Astley, Eccles, Manchester, and Stockport, near which point the coal-field crosses the Mersey and enters Cheshire. The extreme length from Bickerstaffe to Staleybridge is 32 miles, and the average breadth 6 miles. Smaller isolated coal-fields occur at Croxteth Park, Bradford near Manchester, and Burnley. The area of the coal-field, including the Burnley basin, is about 217 square miles.

To what distance the southerly dip of the Coal-measures continues beyond the valley of the Mersey is unknown; but from a consideration of the relations of the Carboniferous, to the newer, formations, I regard it as probable that the beds begin to rise towards the south, and possibly terminate along a concealed axis ranging from Chester towards Congleton, in a direction from west to east. This inferential axis would divide the concealed coal-measures into two distinct basins.

General Succession of Formations.

			Maximum Thickness. Ft.
Trias, 4,750 feet.	Keuper (A, B, of fig. 13).	1. Red Marls, Cheshire ...	3,000
		2. Lower Keuper Sandstone (Waterstones)	500
	Bunter (C. D.)	1. Upper Mottled Sandstone	500
		2. Conglomerate beds ...	650
		3. Lower Mottled Sandstone (often absent)	100

			Maximum Thickness. Ft.
Permian Series, 355–650 feet.	1. Upper (E.)	Red marls and limestones of Leigh, Patricroft, Manchester, with *Schizodus*, *Bakevellia*, *Turbo*, *Rissoa*, *Natica minima*, *Tragos*	250
	2. Lower (F.)	Sandstone of Collyhurst, etc.	100 to 400 or more
Coal-measures, 6,080 feet to 8,000 feet.	1. Upper—(H 1.)	Shales, sandstones, and limestones of Ardwick, with *Spirorbis*, *Leperditia*, and fish of the genera *Ctenoptychius*, *Megalichthys*, *Palæoniscus*, etc.; and a bed of black-band ironstone, with *Anthracosia Phillipsii*. Below these beds are sandstones, shales, and thin coal-seams.	1,680 to 2,000
	2. Middle—(H 2.)	From the Worsley Four-feet Coal to the "Arley Mine," with *Anthracosia*, *Modiola*, fish, etc.	3,000
	3. Lower, or Gannister Beds. (H 3.)	Flags, shales, and thin coals, with Gannister floors and roofs of shale, with *Spirorbis*, *Goniatites*, *Nautilus*, *Aviculo-pecten*, *Lingula*, *Anthracosia*, fish, and Crustaceans (*Leperditia*).	1,400 to 2,000
Millstone Grit		From the "Rough Rock" to the Lowest Millstone Grit (with thin coals)...	3,500 to 5,000
Limestone Shale or Yoredale Rocks, with molluscs ...			2,000 to 4,000

Note.—Several valuable memoirs on this coal-field have appeared by Mr. Binney, "Trans. Geol. Soc.," Manchester, vols. i and ii, Part vii; also by Mr. Bowman (*ibid.*). See also Mr. Dickinson's Vertical Section, in Report of the Inspectors of Mines for 1858. The Geological Survey of Lancashire, on a scale of 6 inches, and of 1 inch to a mile, was completed in 1867, and is illustrated by explanatory memoirs and sheets of sections.

The coal-series varies considerably in different parts of the district, and there is a general thickening of the sedimentary materials, as sandstones and shales, towards the N.N.W. Thus the *same* coal-seams are farther apart at St. Helens than at Prescot; and at Wigan than at St. Helens.

Several coals can be traced over the entire district under different names. The "Little Delf" of St. Helens is the "Arley Mine" of Wigan, the "Riley Mine" of Bolton, and the "Dogshaw Mine" of Bury. It is the lowest coal-bed of the middle coal-series, and one of great economic value. Its roof frequently contains fish remains; and some yards above it there occurs a very constant bed of ironstone filled with *Anthracosia* (*Unio*) *robusta*. Above this is the "Rushy Park" coal, which is very constant; but unfortunately the most valuab e of all the coal-seams, the *Cannel Mine* of Wigan, thins away in every direction from Wigan as a centre. The "Trencher Bone" of Bolton is the "Wigan 9-feet," and the "Roger 9-feet" of St. Helens.

General Section of the Coal-series at St. Helens.

(The numbers show the coals which correspond to each other.)

	Yds.	Ft.	In.
Strata of Upper Coal-measures without coal ...	650	0	0
Lyons Delf Coal (inferior quality)	0	2	8
Strata	16	2	0
London Delf Coal (inferior quality)	0	2	6
Strata	28	2	2
Potato Delf (inferior quality)	0	5	0
Strata	14	0	0
Earthy Delf (unworkable, full of partings) ...	0	4	8
Strata	94	1	0
St. Helen's Main Coal	0	9	0
Strata	10	2	0

		Yds.	Ft.	In.
	Four-Feet Coal	0	3	6
	Strata	18	2	0
	Cannel	0	1	6
	Strata	92	2	0
	Coal	0	3	10
	Clay	1	1	2
	Ravenhead Main Coal	0	7	0
	Strata	33	0	0
	Bastions Mine	0	4	3
	Strata	4	1	0
	Higher Roger Coal (inferior, with partings) ...	0	4	0
	Strata	61	2	0
	Flaggy Delf	0	4	0
	Strata, with Lower Roger Coal	152	2	0
2.	*Rushy Park Coal*	0	4	6
	Strata	54	0	0
1.	*Arley Main* or *Little Delf*	0	3	0

General Section of the Coal-series at Wigan.

		Yds.	Ft.	In.
16.	*Riding Coal of Red Rock Bridge*	0	2	6
	Strata ... ... about	200	0	0
15.	*Ince Yard Coal*	0	3	0
	Strata, with ironstone	51	0	0
14.	*Ince Four-Feet Coal*	0	4	0
	Strata	27	0	0
13.	*Ince Seven-Feet* (with parting)...	0	3	9
	Strata	23	1	0
12.	*Furnace Mine* (with parting)	0	3	9
	Strata	84	0	10
11.	*Pemberton Five-Feet Mine*	0	4	6
	Strata (with a coal-seam 2 feet thick)... ...	25	1	0
10.	*Pemberton Four-Feet Mine*	0	4	0
	Strata	149	0	0
9.	*Wigan Five-Feet* (inferior)	0	4	6
	Strata	21	0	0
8.	*Wigan Four-Feet* (with cannel)	0	4	0
7.	Strata, with a 5-foot 6-inch coal called "Nine-Feet Mine"	125	0	0

		Yds.	Ft.	In
6.	*Cannel* (best gas coal) ... ... from 1 to	0	3	0
	Strata (variable)	1	1	0
5.	*King Coal*	0	3	6
	Strata, with "Ravin Mine"	79	0	0
4.	*Yard Coal*	0	3	0
	Strata	50	0	0
3.	*Bone Coal*	0	2	0
	Strata	3	0	0
2.	*Smith Coal* (Rushy Park)	0	3	0
	Strata	60	0	0
1.	*Arley Mine* (the most valuable next to the *Cannel*) ... ... 3 feet to	0	4	6

General Section between Manchester and Bolton.

(Curtailed from that of Mr. Dickinson.)

		Yds.	Ft.	In
	Upper Coal-measures, with 17 beds of coal, too thin for working	420	0	0
16.	*Worsley Four-Feet Coal* (good)	0	4	3
	Strata, with 25 seams of coal under 2 feet ...	294	0	0
15.	*Bin Coal* (inferior)	0	3	6
	Strata	26	0	0
	Albert Mine	0	3	3
	Strata	14	0	0
14.	*Crumbourke Coal*	0	4	0
	Strata	48	0	5
13.	*Rams Mine* (good)	0	5	6
	Strata, with two coal-seams under 2 feet ...	84	2	7
10.	*White Coal* (good)	0	3	0
	Strata (of variable thickness)	7	0	0
	Black Coal	0	3	0
	Strata ... ... about	15	0	0
9.	*Old Doe Coal* (three beds, with two partings)	0	8	0
	Strata	10	1	0
8.	*Five-quarters Coal*	0	3	6
	Strata (with three coals under 2 feet)... ...	88	2	0
7.	*Trencher Bone Coal* (3 feet 6 inches to 6 feet)	0	5	0
	Strata	34	0	0

		Yds.	Ft.	In.
6.	*Cannel Mine* (cannel only 6 inches)	0	4	6
	Strata	19	1	0
5.	*Saplin Coal* (with parting)	0	4	0
	Strata	35	6	0
	Plodder Coal (coal and shale, variable) ...	0	3	0
	Strata	38	0	0
4.	*Yard Mine*	0	3	0
	Strata (with four thin coals)	56	0	0
2.	*Three-quarters Mine*	0	2	0
	Strata	68	2	0
1.	*Arley Mine* (with parting) ... 3 ft. 6 in. to	0	4	6

The strata here enumerated are characterised by several bands with *Anthracosia.* From the *Cannel,* the late Mr. Peace collected splendid specimens of fish-remains, belonging to the genera *Megalichthys*, *Holoptychius*, and *Ctenoptychius.*

The Lower Coal-measures.—These commence with the flagstones of Up-Holland, which lie a short distance below the Arley Mine, and extend downwards to the Millstone Grit through a series of beds of shale, flagstone, and coal, about 1,800 feet in thickness. They are well laid open in the sections of the Wigan and Liverpool Railway. The coal-seams, three or four in number, are thin ; and amongst the strata overlying the "Upper-foot," or "Bullion-coal," marine fossils of the genera *Goniatites*, *Nautilus*, *Aviculopecten*, etc., occur, as originally described by Mr. Binney.

General Section near Oldham and Middleton.
*Bardsley Colliery.**

	Ft.	In.
"Bardsley Rock" (sandstone)	45	6
Shale	31	7
Stubb's Mine (coal)	1	5
Metal (shale)	25	6
Fairbottom Mine	2	0
Shale (with three seams of coal)	76	6
Park Mine (with parting of clay)	3	6
Shale	29	0
Foxhole Rock	79	8
Foxhole Mine...	2	4
Soft shale	32	6
Cannel	1	6
Strata, principally shale, with a thin coal-seam ...	187	8
Hathershaw Mine	2	2
Shale, with two thin coal-seams	51	0
Sandstone, with water, called "Chamber Rock"	88	6
Shale and sandstone	38	3
Nield, or *Upper Chamber Mine*	2	0
Shale and sandstone	54	6
Lower Chamber Mine (with two shale partings) ...	4	3

The most valuable seam in the district of Oldham, Middleton, and Ashton-under-Lyne, is the "Black-mine," which is generally upwards of 4 feet of solid coal of good quality; and in the Astley colliery at Dukinfield† lies at a depth of 687 yards from the surface. In the direction of the Mersey, where the coal-field passes into Cheshire, the seams are generally thin, or split up by partings of shale, which render them less profitable to work at great depths. From the neighbourhood of Oldham, where the measures begin to bend round towards the south,

* "Geology of Oldham and Manchester," "Mem. Geol. Survey," p. 24.

† "Geology of Oldham and Manchester," "Mem. Geol. Survey," p. 27. This important colliery has now been closed.

the dip is very persistent, and at a high angle in a westerly direction ; the beds here coming under the influence of the Great Pennine axis of upheaval which ranges in a north and south direction along Saddleworth Valley.

The Mountain Mines.—The coal-seams known by this name in the northern and eastern portions of the district lie in the Lower Coal-Measures. Two of them are extensively mined, the "upper mountain mine," from 14 to 16 inches in thickness ; and the "Gannister coal, or lower mountain mine," lying from 60 to 75 yards underneath, varying in thickness from 18 to 30 inches, and in the direction of Burnley to even more than this. Its quality is good, and it is useful for coking : it has been worked at Heywood, Rochdale, the Lancashire moors west of Todmorden, and Portsmouth, Tunshill, Crompton, Broad Car, Staleybridge, and Newton ; and at New Mills and Whaley in Cheshire.

Marine Fossils in the Middle Coal-measures.—In some large concretions shown in the banks of the River Tame, west of Dunkirk colliery, Ashton-under-Lyne, Prof. A. H. Green, formerly of the Geological Survey, discovered a remarkable series of marine fossils, figured and described by the late Mr. Salter, in the "Geology of Oldham."* The position of this stratum appears to be above all the workable coals of Dukinfield. The following are the names of the species from this remarkable band : *Serpulites*, *Aviculopecten fibrilosus* (Salter), *A. papyraceus*, Sow. *Ctenodonta* (allied to *C. tumida*), *Nautilus præcox* (Salter), *Discites rotifer* (Salter), *Discites* (two other species), *Goniatites*, *Orthoceras*, *Megalichthys Hibberti.* This is altogether a unique series from the middle division of the Lancashire Coal-formation

* "Mem. Geol. Survey," pp. 32 and 64 (with plate of fossils, etc.).

in which only fossil molluscs of genera allied to *Anthracosia* are usually found.

Faults of the Lancashire Coal-field.

The Lancashire coal-field is traversed by dislocations which, although of great magnitude, produce scarcely any perceptible features at the surface—so complete have been the effects of denudation in levelling down inequalities arising from the displacement of the rocks. Over the southern portion of the district many of the faults slope or *hade* considerably ; the general inclination being 25 degrees from the vertical, but often more.*

The western boundary of the coal-field is a very large downthrow fault ranging by Ormskirk, where the Lower Keuper Sandstone and Lower Coal-measures are brought into contact ; the displacement at this point must amount to over 1,000 yards.

The Great Up-Holland fault, which brings up the Lower Coal-measures so as to form an elevated band of country between between the coal-fields of Rainford and Wigan, has a throw of 650 yards east of Lord Crawford's collieries.

The coal-measures at Wigan are divided into "belts," bounded by parallel faults which range N.N.W., having vertical displacements varying from 150 to 600 yards ; of these the principal are the "Shevington fault," the "Cannel fault of Ince," and the "Great Haigh fault." Towards Manchester there is the "Great Pendleton or Irwell Valley fault," ranging along the valley of the Irwell (N.N.W.),

* The fault at Red Rock Bridge, north of Wigan, and that which bounds the little coal-field near Rainhill, are remarkable instances of very flat slopes ; the angle being about 25 degrees from the horizontal in each case.

bringing in the New Red Sandstone, with a downthrow on the N.N.E. of upwards of 1,000 yards. Lastly, the great fault along which the Manchester coal-field has been upheaved on the west against the New Red Sandstone has a throw of (at least) 400 yards. All these dislocations appear to have been produced after the period of the Trias or New Red Sandstone, and the resulting inequalities of the surface have since been planed away by agencies of denudation.

Fossils.

Those who are interested in the palæontology of the coal-formation would do well to consult the carefully-prepared lists of fossils, both of vegetable and animal origin, drawn up by the late Mr. Salter, and published in the "Geology of Bolton-le-Moors,"* and in the "Geology of Oldham."† Having referred to these valuable details, I shall content myself with enumerating a few species of general occurrence, most of which were first identified by the late Mr. Edward Binney,‡ to whose indefatigable exertions as a collector geologists of the North of England are so much indebted. More recently, the palæontology of the coal-measures has been described in several papers by Mr. H. Bolton, of the Bristol Museum, and contributed to the Geological Society of Manchester.§

Upper Coal-measures.—Fish of the genera, *Ctenoptychius Megalichthys*, *Diplopteris*, *Palæoniscus*, *Platysomus*, *Rhizodus*

* "Mem. Geol. Survey" (1862).

† *Ibid.* (1864).

‡ "Trans. Geol. Soc.," Manchester, vol. i.

§ "Trans.," vol. xxviii.

Diplodus, and large bony rays resembling those from the limestone of Burdie House in Scotland. Crustacea: *Cythere* (Cypris) *inflata*. Annelids: *Spirorbis carbonarius*. Plants of the usual coal-measure species.

Middle Coal-measures.—Fish: *Palæoniscus Egertoni*, *Megalichthys Hibberti*, *Rhizodus granulatus*, *Holoptychius*. *Diplopterus*, *Pleuracanthus gibbosus*, *Cœlacanthus lepturus*. Molluscs: *Anthracomya modiolaris*, *A. dolabrata*, *Anthracosia ovalis*, *A. acuta*, *A. robusta*, *A. aquilina*, *Anthracoptera Browniana*. Crustacea: *Beyrichia Binneyana*, *B. arcuata*, *Estheria striata*. Annelids: *Serpula* (?), *Spirorbis carbonarius*. Plants: *Asterophyllites*, *Calamites*, *Flabellaria*, *Halonia*, *Knorria*, *Lepidodendron*, *Lepidophyllum*, *Megaphyton*, *Nœggerathia*, *Poacites*, *Primularia*, *Sigillaria*, and *Ulodendron*. *Alethoptesis*, *Cyclopteris*, *Neuropteris*, *Pecopteris*, *Sphenopteris*; and Fruits—*Lepidostrobus* and *Trigonocarpum*.

Lower Coal-measures.—Fish: *Megalichthys Hibberti*, *Cœlacanthus*, *Palæoniscus Monensis*, *P. Egertoni*, *Rhizodus granulatus*, *Pleuracanthus*. Molluscs: *Goniatites Listeri*, *G. reticulatus*, *G. Gibsoni* (Phill.), *G. paucilobus*, *Discites* (sp. inc.), *Orthoceras* (sp. inc.), *Posidonia Gibsoni*, *P. lævigata*, *Monotis lævis*, *Aviculo-pecten papyraceus*, *Anthracosia ovalis*, *A. acuta*. *A. aquilina*, *Anthracoptera*, *Anthracomya*, *Lingula mytiloides*. Crustacea: *Estheria striata*, *Beyrichia arcuata*. Plants: *Alethopteris lonchiticus*, *Calamites Suckowii*, *C. undulatus*; *Daxodylon*, *Lepidodendron Sternbergii*, *L. obovatum*, *L. dilatatum*, *Sigillaria hexagona*, *S. mammilata*, *S. reniformis*, *Ulodendron majus*, *Pecopteris arborescens*, *Alethopteris lonchiticus*, *Neuropteris flexuosa*, *Nœgerathia*,

Resources of the Lancashire Coal-field.

In estimating the resources of this important coal-field, the Commissioners appointed in 1901, namely Professor Edward Hull, Sir George J. Armytage and Mr. Aubrey Strahan,* assisted by Mr. J. Higson, arrived at the following results; the limit of depth of 4,000 feet being the same as that adopted by the Commissioners of 1871.

1. Area of the coal-field, including the Manchester and Burnley districts	217 square miles.
2. Total thickness of strata with coal	6,000 feet.
3. Number of workable seams of 2 feet and upwards in thickness	62
4. **Available quantity of coal** to a depth of 4,000 feet, and including seams of 12 to 24 inches in thickness	**4,238,507,000 tons.**

The quantity of coal raised in this coal-field between the years 1870 and 1903 inclusive, amounted to 687,050,258 tons, and during the last-mentioned year the output amounted to 11,354,756 tons.†

THE MANCHESTER COAL-FIELD.

The north-eastern side and suburbs of Manchester stand upon a small coal-field, entirely enclosed by New Red Sandstone, except at Collyhurst, where it is in contact with Permian strata. The shape of this coal-field is oblong, with its longest diameter lying N.N.W., it is about 4½ miles in length; and in its broadest part it is about 1½ miles across.

South of the fault which crosses it north of Miles Platting,

* Mr. Strahan was appointed in 1903.

† Statistical Returns of the Home Office for 1903.

and on the north side brings in the Permian beds of Collyhurst, the dip of the strata is S.W. The highest beds consist of red clays, shales, sandstones, and six beds of limestone, containing *Spirorbis* and fish; two thin coal-seams, and a bed of black-band ironstone containing in great abundance *Anthracosia Phillipsii*, and scales of fish. Mr. Binney considered this to be identical in position with the black-band ironstone of the Upper Coal-measures of Stoke, Staffordshire. These strata can be traced along the banks of the river Medlock, at Ardwick. The fossils which they contain have already been described (p. 146). Beyond question this is the finest representative series of Upper Coal-measures in the whole of Britain. Below these calcareous beds there occurs a thick series of shales, sandstones, etc., with seven beds of coal, the thickest of which is only 4 feet. One of these coal-seams is probably on a parallel with the Worsley "four feet" mine and its associated strata; but the thick coals, which lie about 1,000 feet below this coal at Pendleton, have not yet been reached in the Manchester coal-field, the intervening strata having apparently thickened out to a great, but unknown, extent.*

Amongst these strata is a bed of calcareous hæmatite which Mr. Binney considered identical with a band of a similar mineral formerly worked at Patricroft Colliery.†

* From a calculation I made some years since, I came to the conclusion that no important coal-seams would be found at a less depth than 616 yards below the Bradford Four-Foot Coal. See "Geology of Oldham and Manchester," "Mem. Geol. Survey," p. 36 (1864).

† "On the Geology of Manchester," "Trans. Geol. Soc. Manchester," vol. i.

CHAPTER XIV.

THE BURNLEY COAL-BASIN.*

LYING several miles to the northward of the main coal-field, but united to it by a ridge of high land formed of Lower Coal-measures, stretching from Rochdale by Bacup in a northerly dirction, is the small but rich coal-basin of Burnley. This coal-basin sets in along the northern side of a low anticlinal arch, which lies along Rossendale Valley, and which, bringing to the surface the Millstone Grit, separates the Burnley basin from the northern margin of the main coal-field. To the north, the basin is bounded by the Pendle Ridge, which ranges in an E.N.E. direction through Blackburn to Colne, along which the Millstone Grit and Yoredale beds rise and crop out at high angles; the dip, however, rapidly lessens on receding from the base of the ridge. Along the east, the boundary of the basin is generally a fault, beyond which the moorlands of Yorkshire, formed of different members of the Millstone and Yoredale beds, rise to considerable elevations. One of these faults

* A valuable paper on the Burnley Coal-basin was read before the Geological Section of the British Association at Manchester, by Messrs. T. T. Wilkinson, F.R.A.S., and the late Mr. Whitaker, both of whom had devoted much attention to its structure, and the organic remains which its strata present. In my survey of this coal-field in 1867–8, I received much assistance from these gentlemen, and also from the late Sir J. Kay-Shuttleworth, of Gawthorpe Hall.

ranges along the Portsmouth Valley, along which the Millstone Grit is brought up on the south side for a long distance, forming a noble, and often precipitous, escarpment. Another fault, parallel with this, ranges through Townley Park, and between them there is a trough, in which the highest coal-seams of the basin are found. In the centre of the basin is situated the town of Burnley itself, under which the strata are nearly horizontal.

A transverse section taken across the ridges of Padiham Heights and Pendle Hill, in the direction of Clitheroe, gives in unbroken succession a complete series of beds from the *Fulledge main coal*, or Arley mine, to the Carboniferous Limestone; and I believe it is the only spot in Lancashire where none of the links in this chain of rocks are absent, or unbroken.

This section includes:—1. The outcrop of the "Arley mine," under Padiham reservoir; 2. The Lower Coal-measures, or Gannister beds, with thin coal-seams; 3. The "Rough Rock" and the beds of the Millstone Grit series; and 4. The Yoredale series, forming the western portions of the Pendle Range, passing downwards into massive encrinital limestone. The whole of this series reaches a thickness probably little short of 10,000 feet.

Thickness of the Carboniferous Series.—Nowhere in the north of England has the Carboniferous formation from the Mountain Limestone upwards attained such proportions in vertical dimensions as in this part of North Lancashire. The upper portion of the coal-formation has been denuded and lost; but, restoring it to its original dimensions as it occurs in South Lancashire, there appears to have been deposited a total thickness of over 18,000 feet of Upper and Middle Carboniferous Rocks, as determined by several

measurements across the Pendle Ridge, which are as follows* :—

	Feet.
Upper Coal-measures (restored, as at Ardwick) ...	2,013
Middle ,, (partly restored)	4,247
Lower ,, (from the Arley Mine to the first Millstone or "Rough Rock")	2,200
Millstone Grit Series of Pendle	5,500
Yoredale Series of Pendle...	4,675
Total	18,635

Succession of Coal-seams at Burnley.

		Thickness. Feet.
	Strata	30
1.	*Doghole Coal*	6
	Strata	21
2.	*Kershaw Coal*	3
	Strata	81
3.	*Shell Coal* (Anthacosia)	2½
	Strata	18
4.	*Main Coal*	5
	Strata	33
5.	*Maiden Coal*	3
	Strata, with eight thin coal-seams (*Anthracosia rugosa*)	162
6.	*Lower Yard*, or *Five-Feet Coal* (with shales)	5
	Strata	21
7.	*Lower Bottom Coal*, or *Four-Feet Coal* ...	3½
	Strata	78
8.	Impure Cannel	2½
	Strata	21
9.	*Thin Coal* and "fish-bed"	2¾
	Strata	66

* E. Hull "On the Thickness of the Carboniferous Rocks of the Pendle Range of Hills," etc., "Journ. Geol. Soc. Lond.," vol. xxiv, p. 319. In the measurement of some of these rocks I was assisted by my colleague, Mr. Tiddeman, of the Geological Survey.

	Thickness. Feet.
10. *Great Mine* { Coal, 28 inches; Shale, 12 ,,; Coal, 19 ,, }	4 (coal)
Strata	201
11. *China Bed*	2
Strata	99
12. *Dandy Bed*	2
Strata	141
13. *Fulledge Main Coal*, or *Arley Mine*... ...	
Lower Coal-measures, with Gannister Coal, and two or three other seams, with roofs containing Goniatites, Aviculo-pecten, etc.	
Millstone Grit Series, with several thin coals.	

From this section it will be seen that, near the centre of the basin, there are 1,017 feet of strata, down to the lowest thick coal, representing the *Arley mine* of Wigan, or the *Royley mine* of Oldham.

At Gawthorpe we find the following section:—

	Ft.	In.
Various strata	43	2
Coal...	1	8
Various strata	57	1
Four-Feet Coal	4	3
Various strata, with hard sandstone, 24 feet thick...	130	0
Yard Coal	3	0
Bing (clay)	9	7
Great, or *Bing Mine* (with parting) ...	6	0
	254	9

Below these are the Arley and Gannister Coals.

The Lower Coal-measures which encircle the basin contain the "mountain mines," which are here of more than

usual importance. The Upper Mountain Mine is about 2 feet or more in thickness, and the Lower, or "Gannister Coal," has generally a thickness of 4 feet. The presence of such seams below the Arley mine adds largely to the resources of this basin. Bands of ironstone also occur, and have once been worked in this district.*

Resources.—The estimates of the resources of the Burnley basin are included with those of South Lancashire.†

In 1867 I made very careful estimates of the resources of the Burnley basin for the Geological Survey, of which the following is an abstract:—

	Tons.
Low Bottom Mine	7,000,000
Fulledge Thin Mine	5,000,000
Great Mine...	12,000,020
Arley Mine	65,000,000
Gannister Mine	100,000,000
Total	189,000,000

Supposing the yield of the Burnley basin since that period to have averaged about 1 million tons per annum, the quantity in reserve at the present time would be about 150 million tons.

The quantity of coal raised in Lancashire in 1903 was 24,517,711 tons from about 565 collieries. Lancashire contains the deepest coal-mines in the British Isles, that of Rose Bridge, near Wigan, 806 yards in depth, that of Dukinfield in Cheshire, on the confines of Lancashire, 717 yards; and that of Pendleton, near Manchester, where the depth

* Mr. E. W. Binney, "Mem. Lit. and Phil Soc.," Manchester, vol. xii.

† I was informed by the late Sir J. Kay-Shuttleworth that coal is known to have been worked at Burnley in the reign of Henry VIII.

of the shaft is 515 yards, but the coal is worked to a total depth from the surface of 1,161 yards, or 3,483 feet, being, I believe, the deepest mine in the British Islands. There are also several shafts varying from 400 to 600 yards in depth in the western part of the coal-field. Several large firms also raise from their own pits nearly one million of tons of coal yearly. In this district mining operations are conducted on a large scale, and with the most perfect mechanical appliances.

Resources of the Lancashire Coal-fields, including that of the Burnley Basin, in 1904.

The system adopted for determining the quantity of available coal down to a depth of 4,000 feet, was as follows:—Copies of a form for tabulating the quantity of coal remaining to be worked, and under separate heads of thickness of each seam, were sent to all the colliery proprietors and lessees of mines in Lancashire and Cheshire, with the request that they would have them filled up and returned, in order that they might be summarised. After some discussion it was arranged that the proprietors should be at liberty to send in their replies, either to Mr. John Higson, one of the leading mining engineers of Lancashire, or to the Geological Survey Office in London. It was considered that the owners and lessees were in a better position to know the amount of coal remaining to be got under their respective holdings, than outside parties; and as each return was accompanied by a map or tracing showing the extent and boundaries of their ground, these were transferred to the ordnance survey map, and thus, ultimately the quantity of coal under the whole mining

district of Lancashire, as far as it was being worked, was made available for calculation.

In some cases it was found that the lessees overlapped under the same extent of surface, and that there were blank spaces to be filled up, either because the coal had been worked out, or because it had not been proved by actual mining. These cases had severally to be dealt with, but as the maps and sections of the Geological Survey on the 6-inch scale were always available for reference, there were few cases in which a solution of the problem could not be arrived at.

Having thus explained the method adopted for estimating the resources of this great coal-field, I proceed to give the results as follows :—

Resources of Available Coal in the Year 1903 *to a Depth of* 4,000 *Feet.*

	Tons.
1. Returns of colliery proprietors sent to the Geological Survey Office, London ...	2,690,577,413
2. Returns sent to Mr. Higson, Manchester ...	512,547,446
3. Addition for "Mountain Mines" not included in the returns	189,754,667
4. Areas not included in any returns for which the quantity of coal was estimated* ...	1,005,182,300
	4,396,061,826
5. Deduct for quantity below 4,000 feet included in the returns	162,048,920
Total available coal	**4,236,048,906**

* These areas were not covered by any returns.

Comparing this result with that arrived at by the Commission of 1870–1, we shall find that there is a very close agreement, as follows :—

Results of 1870–1.

	Tons.
Quantity of coal available above 4,000 feet in depth	5,345,620,000
Deduct for quantity worked out since 1870 ...	687,050,259
Leaving at present	**4,658,569,741**

The difference is thus 422,521,000 tons in excess, as estimated by the Commission of 1870, and though this in itself seems a large figure, it will be seen that from both returns there still remains a large supply. We cannot, however, overlook the fact that the amount of coal is being very rapidly used up; the quantity raised in Lancashire in 1903 being 24,517,711 tons, so that at the rate of production for this year the supply would only last for about 173 years.

I admit that there are large quantities remaining under the 4,000 feet limit which will tend to prolong the period; but we must recollect that only seams of good quality, and of a thickness exceeding (say) 3 feet, would be workable at depths of 4,000 to 5,000 feet. Fortunately Lancashire possesses ten or twelve seams coming under this head, so that the future supply is likely to be more extended than might appear from the results arrived at by the Commission of 1904, provided the physical obstacles to mining beyond a depth of 4,000 feet can be overcome.

CHAPTER XV.

PARK GATE COAL-FIELD, CHESHIRE.

A NARROW band of dark colour on our geological maps, stretching for upwards of a mile along the eastern shore of the estuary of the Dee, marks the position of the Park Gate Coal-field. From its position with reference to the coal-field on the opposite shore, we can scarcely doubt but that it is connected with the Flintshire coal-field under the sea; and the coals have actually been worked seawards for some distance. The general dip of the coal-strata is southwards and westwards; and inland they are separated from the New Red Sandstone by a large fault which enters the sea at the north side of Burton Point, where a very interesting section of this latter formation is exhibited in the cliffs. The following is a section of the coal-series, for which I am indebted to my friend Mr. John Higson, of Manchester:—

Section of the Coal-series, Park Gate.

	Yds.	Ft.	In.
Strata	23	0	5
Coal	0	2	0
Strata	3	0	7
Coal (*Main-seam*)	1	2	8
Strata	14	0	0
Coal	1	1	0

It has been suggested that these seams correspond with the "Brassy," "Main," and "Lower Fourfoot" coals of Flintshire.

CHAPTER XVI.

INGLETON AND BURTON COAL-FIELD, NORTH LANCASHIRE.

THIS is a small coal-field, lying a short distance to the south of Kirkby Lonsdale, and to the E.N.E. of Lancaster.* Its relations to the surrounding rocks and its own structure are obscure, owing to the deposit of Drift clay and gravel by which it is overspread.

Along the north-east it is bounded by the "Great Craven Fault," which brings up the Lower Carboniferous Rocks; in the other directions it reposes on beds of Millstone Grit and Yoredale series, and is partially overlain by red sandstones and breccias, which are laid open in the valley of the Lune, and referred by the Geological Surveyors to the Permian formation.† The beds of coal have hitherto only been worked on a small scale.

The following is a section of the coal-series as given by Prof. Phillips, from the notes of Mr. Hodgson, mining engineer :—

* It has been described by the late Professor Phillips, in his "Geology of Yorkshire," and more recently by Mr. Tiddeman, of the Geological Survey, in a communication to Professor Ramsay, which is inserted in his report "On the Possibility of finding Coal under the newer Formations," etc.—"Rep. Coal-Commission," vol. i, p. 127 (1871).

† Geol. Survey Map, Sheet 98, S.E.

	Ft.	In.
Measures	82	0
Coal	1	0
Measures	31	0
Coal	1	0
Measures	4	0
Main, or *Four-Foot Coal*	4	0
Measures	4	0
Coal	2	0
Measures	28	0
Crow Coal	1	8
Measures	54	0
Deep Coal	6 ft. to 9	0
Measures	3	0
Coal	2	0
Measures	80	0
Coal	2	0
Potter's clay	4	0

CHAPTER XVII.

CUMBERLAND COAL-FIELD.

THE zone of Carboniferous rocks which wraps round the northern flanks of the Cumberland mountains is surmounted by the rich coal-field of Whitehaven, Workington, and Maryport. Between this last town on the north and St. Bees' Head on the south, it stretches along the coast of the Irish Sea, and extends inwards for a distance of 5 miles, in which direction the beds rise and crop out. From Maryport the coal-field extends eastward to Bolton. Its total length is about 20 miles, and greatest width, at Workington, about 5 miles.*

From the Memoir of Prof. Sedgwick, who has recorded the distinctive features of this coal-field, I gather the following descending series.†

Succession of Strata.

Permian strata—1. Sandstones of St. Bees' Head, decomposing into grotesque and castellated forms.

2. Gypseous marls, surmounted by sandy marls and micaceous sandstone.

3. Conglomerate of magnesian limestone, etc., resting on an eroded surface of the Whitehaven sandstone.

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* Ruthven's Geological Map of the English Lakes.

† "Trans. Geol. Soc. of London," vol. iv. "Brit. Assoc. Report," vol. vi, p. 75 (1837). I have also been kindly assisted by Mr. Dickson, of Whitehaven, who has furnished several colliery sections and much general information.

Coal-measures—1. (?) Massive reddish sandstone of Whitehaven.
2,000 feet. Prof. Sedgwick appears doubtful of the affinities of this rock—100 to 150 feet.*
2. *Middle*, most fully developed at Cleat Moor, containing seven workable coal-seams.
3. *The Lower*, with four or five thin and inferior coal-seams.

1. Grits and limestone shales, with thin bands of coal at Hesket New Market. The limestone at Cleator and Wath very rich in hæmatite iron ore.

Succession of the Coal-seams.

Whitehaven.

		Thickness. Feet.
	Strata	432
1.	*Yard Band* (about)	3
	Strata	30
2.	*Coal*	$2\frac{1}{2}$
	Strata, with a coal-seam	78
3.	*Bannock Band*	8 to 9
	Strata	60
4.	*Main Band*	6 to 11
	Strata	240
5.	*Low Bottom Coal*	4

Workington.

		Thickness Feet.
	Strata	132
1.	*Fiery Band*	2
	Strata	96
2.	*Brassy Band*	$2\frac{1}{4}$
	Strata	72
3.	*Cannel*, or *Metal Band*	4 to 6
	Strata	60

* After a personal inspection of this sandstone, I feel no doubt of its belonging to the coal-measures.

	Thickness Feet.
4. *Bannock Band*	$5\frac{1}{2}$
Strata	30
5. *Little Main Band*	3 to 4
Strata	180
6. *Main Band*	9 to 10
Strata	210
7. *Yard Coal*	2 to 3
Strata	102
8. *Four-Feet Coal*	4
Strata	150
9. *Udale Band*	3 to 4

At Maryport, beneath the Lower Red Sandstone, there occurs the "Ten-quarter coal," 7 feet thick, supposed to represent the "Bannock Band" of Workington, and the "Metal" and "Cannel bands," separated by 36 feet of strata, are considered to represent the "Main band."

The thick coals of Workington are thrown out south of that town by a large fault, upheaving the Lower Coal-measures, which occupy an extensive plateau, stretching from Harrington to the hills north of Moresby. Another great fault, with a downthrow on the south-west, again brings in the productive measures of Whitehaven. Unfortunately, however, between this fault and the village of Parton, the beds dip to the east, so that all the coal-seams below high-water mark crop out under the sea, and the coal cannot be extracted on account of the quantity of sea-water which finds its way along the planes of bedding. In one of the collieries at Whitehaven, however, the coal has been followed for 3 miles under the sea.*

From Workington to Flimby, a large unwrought coal-field is supposed to exist, and from Workington to Mary-

* As I am informed by Sir Lindsay Wood.

port the general dip of the strata is north-west, and the coals crop out inland, where they have been worked to some extent in very early times.

From Maryport to Bolton, by Crosby and Aspatria, the coal-seams are overlaid by the newer strata of Permian age, under which they probably extend for some undefined distance, which Prof. Ramsay considers may reach as far eastward as Carlisle*—and northward, so as to join the little coal-field of Canobie, which, according to the report of Prof. Geikie, contains eight seams of coal, having an aggregate thickness of 42 feet.†

Resources.

The estimates of the quantity of available coal in 1903 were entrusted to Sir Lindsay Wood, who has included the coal of all seams of 18 inches and upwards, to a distance of 5 miles from high-water mark, under the Irish Sea, and of 12 inches and upwards under the land; and it should be stated that all the coal lies at a less depth from the surface than 2,000 feet. The following are the results:—‡

* "Report of Coal-Commission," vol. i, p. 140.

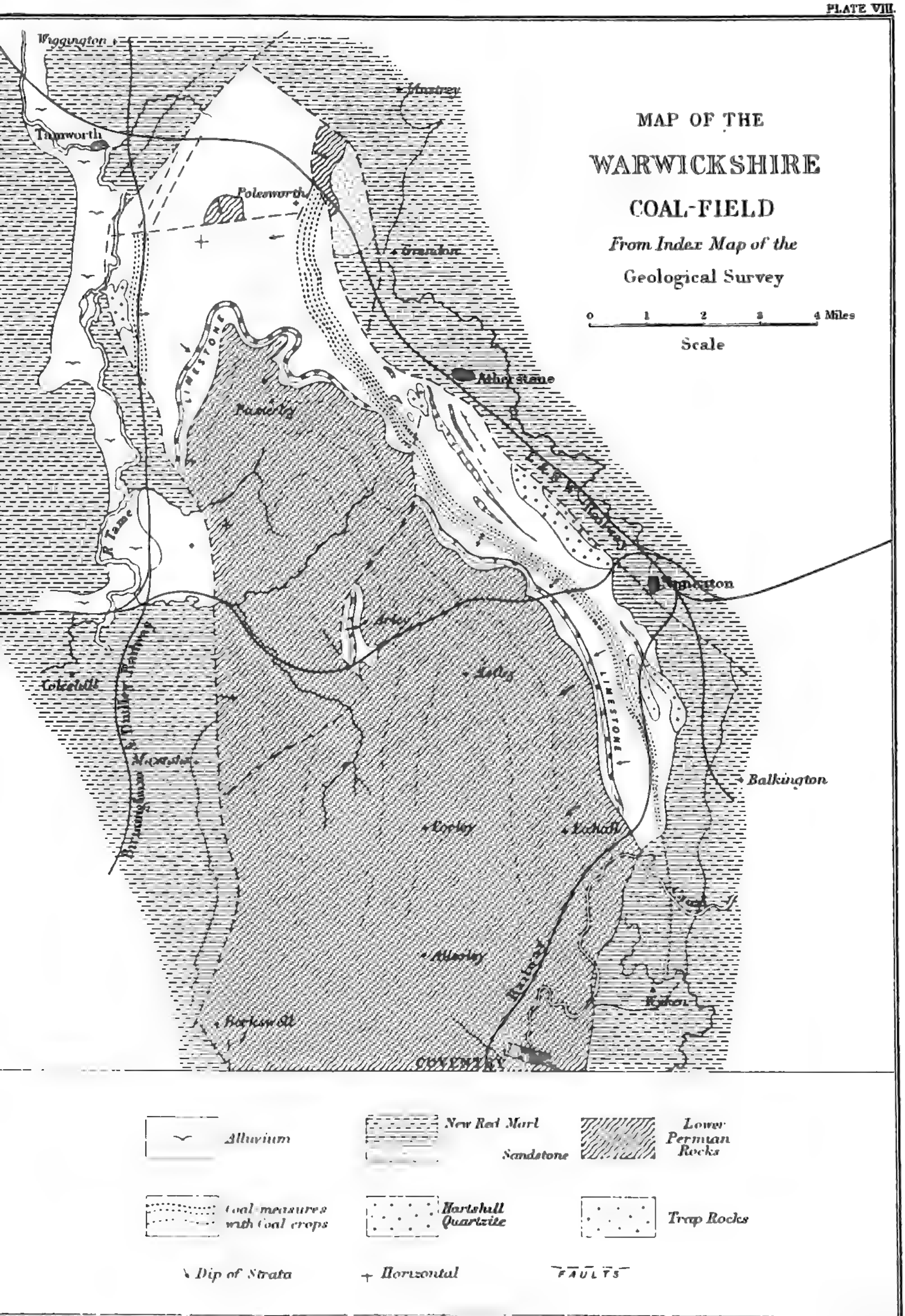
† "Report of Coal-Commission," vol. i, p. 168.

‡ Sir L. Wood has added to his estimate a purely imaginary quantity of coal at a distance of between 5 and 12 miles from the land under the Irish Sea; but, as the evidence for this was absolutely *nil*, the Geological Committee were unable to accept it.

Resources of the Cumberland Coal-field.

	Tons.
Seams of 12 to 18 inches on land	27,070,138
Seams of 18 to 24 inches on land	58,869,293
Seams of 24 inches and upwards on land	505,549,461
Total on land	591,488,892
Seams of 18 to 24 inches under the sea	76,875,000
Seams of 24 inches and upwards under the sea ...	859,345,000
Total under the sea	936,220,000
Total coal remaining unworked ...	**1,527,708,892**

In the year 1903 the quantity of coal raised from Cumberland was 2,207,476 tons; on the basis of this output, the supply would last for about 700 years. Sir L. Wood acknowledges the valuable assistance received from Mr. T. E. Forster, grandson of the Commissioner, who took part in preparing the estimates for the Commission of 1871.



Stanfords Geog[l] Estab[t] London.

London: Hugh Rees, Ltd.

CHAPTER XVIII.

WARWICKSHIRE COAL-FIELD.*

THIS is the nearest to the metropolis of all the coal-fields. It extends towards the S.S.E. of Tamworth, in a constantly narrowing band, by Atherston and Nuneaton, to near Wyken—a distance of 15 miles. At the northern end the strata form a trough 4 miles in breadth, bounded on the west, north, and east by faults which bring in the New Red Sandstone. The coal-measures dip under a large district occupied by Lower Permian rocks, extending under Coventry and Warwick. This tract, with an area of 90 square miles, is underlaid by coal at a depth probably not greater than 3,500 feet in any part, often much less. At the south end of the coal-field the whole of the coal-measures are overlapped by the New Red Sandstone,

* For details of this coal-field, see Mr. Howell's Memoir "On the Geology of the Warwickshire Coal-field, etc.," and the Maps and Sections of the Geological Survey. The section of the coal-field is reduced from No. 5, Sheet 51, by Mr. Howell.

Fig. 14.—SECTION ACROSS THE CENTRE OF THE WARWICKSHIRE COAL-F LD. Length about 6 miles.

At Arley occurs the outcrop of Limestone with *Spirorbis*.

which passes across the edges of the beds and rests upon the Permian rocks. The prolongation of the coal-seams under the Trias has been proved as far south as Wyken Colliery, about 2 miles E.N.E. of Coventry. How much farther south they may extend it is impossible to say; but the probabilities are, that at some distance in the same direction the coal-seams will be found to terminate against the same bank of Silurian rocks, which forms the southern limit to the coal-seams of South Staffordshire; and to become depreciated in quality.*

General Succession of the Formations.

		Maximum Thickness. Feet.
Trias.	1. Red Marl (Keuper)...	600
	2. Lower Keuper Sandstone	180
	3. Bunter Sandstone, only sparingly represented towards the north.	
Lower Permian Rocks.	1. Brown and purple sandstone and marl, with calcareous breccia and conglomerate, with *Strophalosia? Labyrinthodon*, and plants	2,000
Coal-measures.	1. Sandstones and shales, at the base of which is a band of limestone, with *Spirorbis carbonarius*	50
	2. Coal-measures, with five workable coals lying near the centre of the series ...	1,400
	3. Lower Coal-measures unproductive of coal, and traversed by sheets of basalt	1,500
Cambrian Beds.	1. Hard siliceous rock, with bands of shale, altered by intrusive trap (about) ...	500

* This is the view expressed by Prof. Ramsay, F.R.S., in his Report on the "Probability of finding Coal under the Permian and New Red Sandstone." "Report Coal Commission," vol. i, p. 129."

Coal-seams.—The five workable coals lie about 600 feet below the "*Spirorbis* limestone." At the northern end of the district they are separated by about 120 feet of shales and sandstones, which all decrease in thickness southwards, while the coals remain nearly the same; and at Wyken, near Coventry, the five seams combine to form one bed 26 feet in thickness. South of Griff colliery, the Ryder, Bare, Ell, and Slate seams unite to form one seam, known as the "Hawkesbury" coals, which are worked as far south as Wyken and Craven, under the Keuper sandstone, for a distance of 2 miles beyond the south end of the visible coal-field, where they are said to show signs of a tendency to deteriorate, and eventually to die out towards the south. This is a change parallel to that which occurs in South Staffordshire in the case of the "*thick coal*," which becomes split up northwards from Wolverhampton. Both cases exemplify in a remarkable degree the greater persistency of coal-beds over the sedimentary strata with which they are associated.

Under the Permian rocks there is about an equal quantity of coal at a depth of less than 2,500 feet, and about four times as much at a less depth than 4,000 feet. Mr. Howell's sections show the probability that the coal-seams lie very regularly, and nearly horizontally under this formation. Within the last 30 years, great advances have been made in working the coal-seams below the newer formations. Two new colliery shafts, namely, that of Newdigate colliery, and that of the Tunnel colliery (near Stockingford), have been sunk beneath the Permian beds into the coal-seams, and are being successfully worked.* I cannot, therefore, but regard as of peculiar value this vast reservoir

* "Report Coal-Commission" (1904).

of fuel lying at the borders of the south-eastern counties, and actually closer than any other coal-bearing district to the metropolis of Britain.

The Lower Coal-measures are traversed by several intrusive sheets of diorite,* which *nearly* correspond with the planes of bedding. These dykes have been injected subsequently to the deposition of the coal-measures, as they have baked and blanched the shales with which they are in contact. At the base of these strata we find the Cambrian beds in the form of quartzite and schist of Hartshill. Beyond this the whole of the strata are broken off by a great fault, which introduces the Upper Trias to the eastward, consisting of the Keuper Marl and sandstone.

Resources.

The investigation into the resources of the Warwickshire coal-field was entrusted to the Commissioners, Prof. Lapworth and Mr. Sopwith.†

1. Area of coal-field (between the boundary of the Permian formation and the outcrop of the "Seven-Foot" Coal)	30 square miles.
2. Thickness of coal	from 26 to 30 feet.
3. Tonnage remaining unworked	919,362,000 tons.
4. Net available tonnage (visible)	396,936,000 ,,
5. ,, ,, in marginal	449,636,000 ,,
Total	**846,572,000** ,,

* These rocks have been microscopically examined by Mr. S. Allport, who finds them to be "ordinary diorites," hornblende being the prevalent pyroxenic mineral, while augite, olivine, etc., are also present.—"Quart. Journ. Geol. Soc.," November, 1879.

† The depth is under 3,000 feet for the whole quantity.—"Report Coal-Commission," vol. i, p. 31.

The quantity of coal raised in 1903 was 3,449,068 tons from 36 collieries. Considering the advantageous position which the collieries occupy with reference to the London and central markets, it is probable that a great future is in store for this coal-field. A new colliery has recently been opened on the property of Mr. Newdegate, M.P., near Packington, as already stated, and another is in course of construction at Arley, in the Upper Coal-measures, surrounded by a large area of Permian strata, under which the coal-measures are undoubtedly present. The Arley coal-field is an "inlier," which owes its existence to a fault bringing the coal-measures up against the Permian beds on the east side, but its exact course, and the local amount of its displacement (throw) are uncertain; but its general effect is to break-up the central syncline of the Permo-Carboniferous beds into two subordinate synclinal axes of no great importance.*

* "Report Coal-Commission" (1904).

Fig. 15.—SECTION ACROSS THE LEICESTERSHIRE COAL-FIELD.
Distance about 12 miles.

WEST. EAST.

4. Keuper Sandstone and Marl. 2. Middle Coal-measures, with coal. P. Porphyry } Cambrian Rocks of
3. New Red Conglomerate. 1. Lower Coal-measures. S. Slate } Charnwood Forest.
× Faults.

CHAPTER XIX.

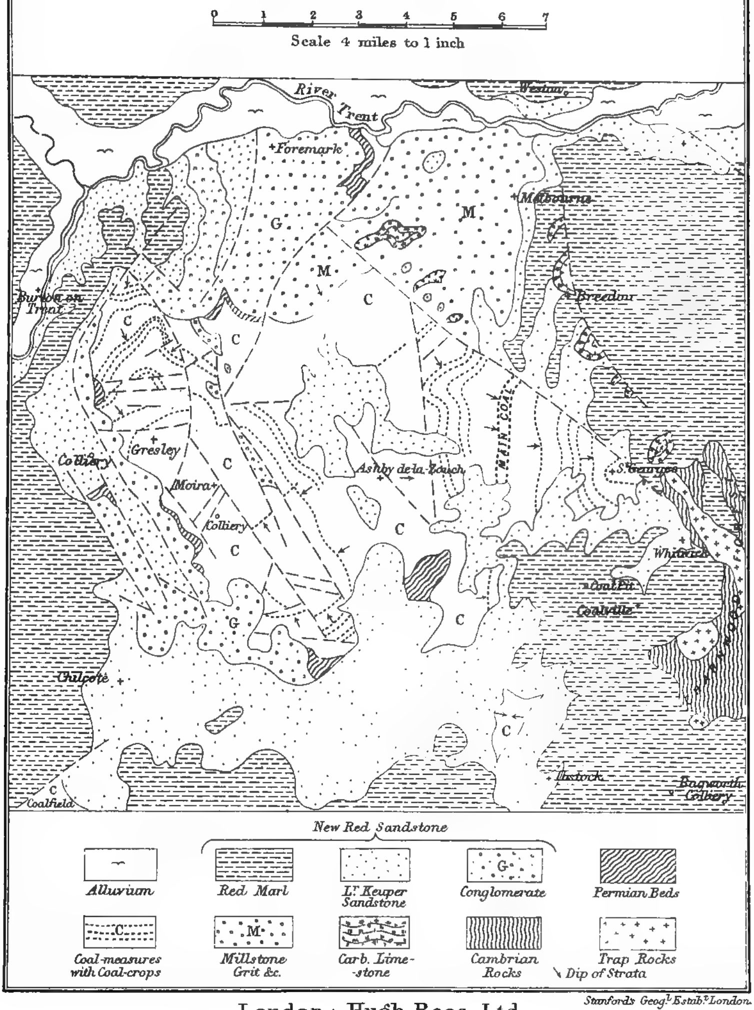
THE LEICESTERSHIRE COAL-FIELD.*

THIS small but valuable coal-field occupies an irregularly-shaped district south of the Valley of the Trent. Along its western, northern, and southern sides, it is bounded by strata of the age of the New Red Sandstone; and along the north-east, by the ancient slates and porphyries of Charnwood Forest, which form a miniature mountain range, rising in rugged knolls and serried ridges above the general level of the country. The coal-measures underlie the New Red Sandstone to a large and unknown distance towards the south and west;

* This coal-field has been very ably illustrated by Mr. Mammatt, in his "Geological Facts," and more recently by the works of the Geological Survey, consisting of Map 63, N.W., 71, S.W.; Horizontal and Vertical Sections; and a Memoir "On the Geology of the Leicestershire Coal-field," by the Author, 1860. The late Rev. W. H. Coleman has also largely contributed to the knowledge of a district of peculiar geological interest.

PLATE IX.

MAP OF THE LEICESTERSHIRE COAL-FIELD



Stanford's Geog.l Estab.t London.

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and in the Coleorton district, several collieries are situated upon the Keuper Red Marl, and pierce this formation downwards to the coal beneath; the deepest of these shafts is at Bagworth colliery. Along the line of the great fault, along which the Cambrian rocks of Charnwood Forest are upraised, the coal-seams rise into a vertical position, and are overlain unconformably by the Keuper Marls.

The coal-field is physically divisible into three districts —that of Moira, on the west; Ashby-de-la-Zouch, in the centre; and Coleorton, on the east. The central district is formed of Lower Coal-measures, without workable coals, and is bounded on both sides by down-cast faults, which introduce the workable coal-beds of Moira and Coleorton. The coal-series of these latter districts cannot be identified with each other, though they are probably synchronous. "The main-coal" of Moira is from 12 to 14 feet thick; that of Coleorton, from 6 to 8 feet.

General Succession of Formation—Leicestershire.

		Feet.
Trias	Keuper Series of sandstone and marl ...	700
	Bunter conglomerate (sometimes absent) ...	200
Permian Rocks :	Breccia, sparingly represented.	
Carboniferous Series	1. Upper Sandstone (unconformable).	
	2. Middle Coal-measures, with about 20 coal-seams, of which 10 are workable	1,500
	3. Lower Coal-measures, unproductive ...	1,000
	4. Millstone Grit	50
	5. Yoredale Series and Carboniferous Limestone.	

The following is a list of the coal-seams in both the Moira and Colcorton districts :—

Coal-seams of the Leicestershire Coal-field.

Moira District—(West).	Ft.	In.	Coleorton District—(East).	Ft.	In.
Ell Coal (*b*)	3	8	Stone smut (*c*)	4	9
Dicky Gobbler (*b*)	3	6	Swannington (*a*)	3	7
Block Coal (*a*)	3	6	Slate-coal (*b*)	4	8
Little or Four-Feet (*a*) ..	4	6	Coal	2	10
Cannel (*b*)	3	6	Coal	3	7
Main { Over Seam / Nether Seam } ...	12	0	Main-coal (*a*)	6	0
			Upper Lount (*b*)	3	9
Toad (*c*)	3	6	Second Lount (*b*)	3	0
Little Woodfield (*c*)	2	6	Middle Lount	4	6
Woodfield (*b*)	5	0	Nether Lount	4	6
Stockings (*c*)...	9	0	Heath End Coal and Cannel	10	0
Eureka (*a*)	4	6	Lower Coal-measures.		
Strata below this unproved.					

In the above list, I have omitted several of the least important coals. The letters *a*, *b*, *c* indicate the degrees of quality.

I shall conclude this account of the Leicestershire coal-field by stating a few geological facts of interest.

Igneous Rocks.—At Whitwick, a remarkable sheet of dolerite or melaphyre, locally called "whinstone," intervenes between the coal-measures and the New Red Sandstone.* In one of the shafts of Whitwick colliery it is 60 feet thick, and has turned to cinders a seam of coal with which it comes in contact. It has evidently been poured out as a sheet of lava over the denuded surface of the coal-

* This rock has been microscopically examined by Mr. S. Allport, F.G.S., who finds it to be composed of triclinic felspar (probably Labradorite), augite, titanto-ferrite, and olivine.—"Geol. Mag.," vol. vii, p. 160 (1870). It is therefore an old dolerite or melaphyre, of later date than the coal-measures on which it rests unconformably, and older than the New Red Sandstone (or at least than the Keuper), and therefore referable, in all probability, to some part of the Permian period.

measures at some period prior to that of the Trias,* and from a vent, probably situated at the junction of the coal-measures with the old rocks of Charnwood Forest. The mutual relations of these rocks I have endeavoured to illustrate in the Geological Survey Memoir of this district.†

Rock-faults.—In the same district, the main-coal has been extensively invaded by channels filled up with fine sand, which completely replaces the coal over several hundred yards. One of these banks of sandstone, at Pegs-green colliery, was found to be 80 yards in width. It is composed of the same sandstone that forms the roof of the coal itself. In another of these, south of Whitwick colliery, a tunnel was driven to a distance of 110 yards without passing through it. These phenomena are similar to those already described in the case of the coal-field of the Forest of Dean.

Salt-water.—In the main-coal of Moira, especially in the Bath colliery, at a depth of 593 feet, salt-water, beautifully clear and of nearly the same composition as sea-water, trickles down from the fissures where the coal is being extracted. The brine is carried to Ashby-de-la-Zouch in tanks, and is considered highly beneficial in scorbutic and rheumatic affections.

* George Stephenson, the inventor of the locomotive engine, under whose direction the Whitwick shafts were sunk, had the sagacity to perceive that neither this layer of whinstone, nor yet the Triassic sandstones and marls which overlie it, interfered with the existence of coal beneath; so that, to all the doubts that were suggested during the progress of the works, he only returned the answer, "persevere." At length the shaft passed through the whinstone, and the coal-measures were reached beneath, greatly to the astonishment of all beholders.

† "Geology of the Leicestershire Coal-field," Fig. 8, p. 45.

Resources.

The estimates of the resources of this coal-field, furnished by the Royal Coal Commission, were entrusted to Prof. Lapworth and Mr. Sopwith, and are arranged under three districts as follows :—

	Tons.
1. Coleorton District—	
Estimated quantity of coal remaining unworked	1,163,793,000
Total deduction for loss, etc.	212,544,000
Net available quantity for future use	951,249,000
2. Ashby District—	
Available quantity for future use	59,987,000
3. Moira District—	
Estimated quantity of coal remaining unworked	1,198,239,000
Total deduction for loss, etc.	384,018,000
Net available quantity for future use	814,221,000
Total available supply	**1,825,458,000**

The above quantities are divided into "visible" and "marginal," of which the former is about one-third of the latter; this is overlain by the Triassic and Permian formations.

The returns sent in by the late Mr. John T. Woodhouse in 1871, gave the available quantity of both districts (Moira and Coleorton) at 339,574,841 tons. As Mr. Woodhouse had an intimate knowledge of the coal-field, we may account for the difference in the estimates by supposing that larger areas of the concealed coal-field have been included by the Commissioners for 1904.

Fossils.—The plant remains are abundant, and have been figured in Mammatt's "Geological Facts." *Goniatites* and other marine forms have been observed in the Lower Coal-measures. Mr. W. Molyneux describes the occurrence of

Orthoceras, *Goniatites Listeri*, *Aviculo-pecten*, *Posidonia*, and *Lingula*, in the shale roof of the "main-coal," where it was reached in a shaft below the New Red Sandstone and Permian beds beyond the limits of the coal-field near Overseal. He also points to the apparent connection of these forms with the occurrence of salt water in the "main-coal" itself, which he believes to be that of the original sea—locked up in the rock between two layers of impervious clay, one above, the other underneath the coal.*

Shells of the genus *Anthracosia* are not uncommon, and a species of *Leperditia* (L. *arcuata* Bean.) has been noticed by Prof. A. H. Green.

* "Rep. Brit. Assoc.," 1877.

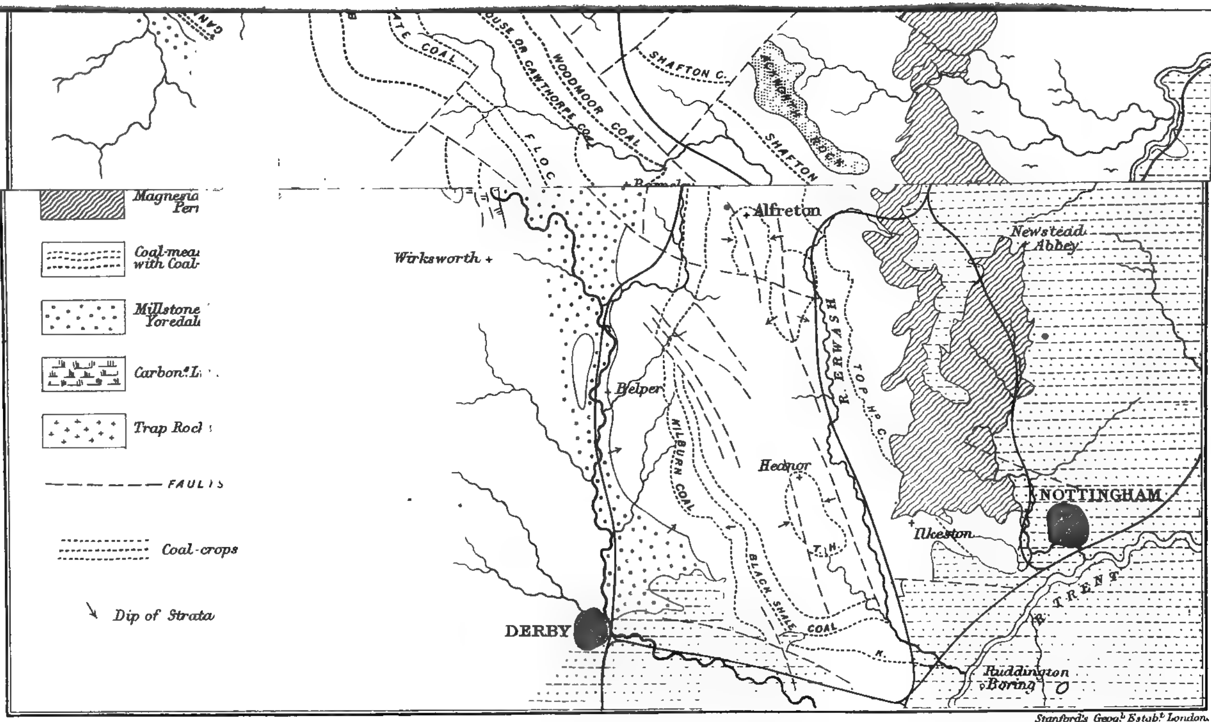
CHAPTER XX.

NOTTS, DERBYSHIRE, AND YORKSHIRE COAL-FIELD.

THIS great field, though forming parts of the shires of Derby, Nottingham, and York, is physically *one;* and in treating of its structure and resources we must ignore political and social landmarks. It is the largest coal-field in England: and about 150 square miles smaller in area than that of South Wales.

Its eastern margin is defined by the escarpment of the Magnesian Limestone, with its subordinate Lower Permian Sandstone, which, commencing near Nottingham, extends northwards beyond the limits of the coal-field itself.* Upon reaching the crest of the escarpment, you find yourself on the edge of a table-land, resembling that of the Oolite Limestone of Gloucestershire, but less lofty. One prominence of this ridge is crowned by the turrets of Bolsover Castle. The southern boundary is formed of New Red Sandstone, and the strata crop out westward as far north as Bradford and Leeds, where they bend round to the east, and finally disappear under the Magnesian Lime-

* On approaching the valley of the Trent the Permian Beds become attenuated and debased; the Magnesian Limestone passes into a yellow calcareous sandstone, and the Lower Sandstone is but feebly, if at all, represented. All this is in consequence of the near approach of the formation to its original margin, formed by the uprising of the Lower Carboniferous, and still older, rocks of Charnwood Forest, above the sea level of the period.



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stone, which passes over, and rests directly, on the Millstone Grit. The greatest length of the coal-field from south to north is 66 miles; and its breadth varies from 5 to 20 miles. Though the general dip of the strata is eastward, there generally occurs along the centre of the field a gentle undulation (shown in the section, Fig. 16), which for a certain distance produces a westerly dip; but in Derbyshire the strata generally roll over to the east when approaching the base of the Permian Rocks. In Yorkshire, their relations are variable. The coal-seams are only occasionally broken by faults except towards the north-western margin.

To the westward, the Lower Carboniferous series rises into the lofty ranges of the Pennine Chain, forming a natural division between the counties of Stafford and Lancaster on the west, and Nottingham and York on the east, as well as for their respective coal-fields. In fact, the upheaval of the Lower Carboniferous rocks, and the supervening denudation, has rent asunder a coal-field which originally embraced the whole of that portion of the North of England extending from the coast of Lancashire and Cheshire

Fig. 16.—GENERAL SECTION ACROSS THE DERBYSHIRE AND YORKSHIRE COAL-FIELD.
Drawn along the border of the two counties into Notts.
Distance 25 miles.

WEST. EAST.

COAL MEASURES.

6. Carboniferous Limestone. 5. Yoredale Rocks. 4. Millstone Grit. 3. Coal-measures, with coal.
2. Magnesian Limestone, etc. 1. Trias.

across to an undefined margin, which probably corresponded pretty nearly with the line of the River Trent, or even stretched farther eastward.

The loftiest escarpment of this central chain is Mickle Fell, formed of Millstone Grit, which reaches an elevation of 2,600 feet; the table-land of Kinder Scout, in the district of the High Peak, lying in the centre of the great arch of Millstone Grit, between the Cheshire and Derbyshire coal districts, is about 2,000 feet;* and in one place the Carboniferous Limestone of Derbyshire rises 1,533 feet above the sea.

Historical Notices.—This great coal-field and its bordering formations have been the subject of several important notices bearing on their mineral structure. As far back as 1684, Lister, whose name has been immortalized by Phillips in the well-known fossil *Goniatites Listeri*, proposed to the Royal Society the construction of geological maps, and illustrated his views by reference to the formations of Yorkshire, and the divisions he would have pourtrayed.† After him (1778) Whitehurst published some good sections of Derbyshire.‡ A few years later the Board of Agriculture, with the assistance chiefly of Mr. W. Smith, published a series of geological maps embracing parts of Yorkshire, Derbyshire, and Notts; and shortly after the commencement of the nineteenth century, Mr. Farey produced his well-known report on the mineralogy of Derbyshire. With the publication of William Smith's Geological Map of England, in 1815, we enter upon the modern epoch of our

* See "Geology of Stockport," etc., "Mem. Geol. Survey," p. 12.

† "Philosophical Transactions," 1684.

‡ In the work entitled "Inquiry into the original state and formation of the Earth," by John Whitehurst.

science, which has been enriched, as far as regards the region we are now investigating, by the labours of Phillips,* Sedgwick,† and Binney.‡ The Government Geological Surveyors have also completed the detailed survey of this coal-field; and have produced an elaborate memoir on the Geology of the Yorkshire coal-field.§

Succession of Strata.

Southern Extremity—Derbyshire and Notts.

The succession of strata along a line drawn from Kirkby Woodhouse through Alfreton Common and Wingfield Manor to Crich, may be very clearly ascertained, both from the details of the collieries, and the natural sections which present themselves. The following is the series in descending order: ‖—

		Feet.
Permian Rocks	1. Marls and sandstone	40
	2. Magnesian limestone (lower bed) ...	60
	3. Marls and sandstone	30
Middle Coal-measures, with coal-seams, 2,500 feet	Strata to Top Hard Coal ... ...(about)	700
	Waterloo Coal	1,600
	Ell	
	Lower Hard	
	Furnace	
	Black Shale or Clod	
	Kilburn	
	Shales, with ironstones	

* "Geology of Yorkshire."

† Papers published in the "Transactions of the Geological Society of London" (1826).

‡ Papers published in the "Lit. and Phil. Soc.," Manchester, etc. Another work requiring notice is Mr. Denny's "Fossils of the Yorkshire Coal-field," "Proc. Geol. Soc.," York, vol. ii.

§ "The Geology of the Yorkshire Coal-field," by Prof. A. H. Green, Mr. Russell, and several assistants (1878).

‖ Horizontal Sections of the Geological Survey, Sheet 60.

		Feet.
Lower Coal-measures, or Gannister Series	Flagstones of Wingfield Manor. Shales and flaggy sandstones, with two coals underlaid by Gannister floors ...	1,000

The above are underlaid by Millstone Grit and Yoredale beds. These strata, in their extension southwards towards the valley of the Trent from Ambergate, gradually bend round towards the S.E., having a north-easterly dip, with which they pass beneath the New Red Sandstone, under which formation their presence has been proved by the opening of a colliery near the bank of the Trent opposite Wilford Church, and by the boring at Ruddington, where the "Alton seam" was reached at a depth of 1,056 feet from the surface, below the Keuper Marls.

In comparing the above series with that on the Lancashire and Cheshire side of the Pennine anticlinal, it is to be remarked, that while there is a general diminution in the total thickness of the strata, they can unquestionably be correlated from the Millstone Grit up into the lower beds of the Middle Coal-measures. Thus, the uppermost Millstone Grit is identical with the "Rough Rock" of Lancashire. The coal-seams of the Lower Coal-measures, and the flagstones of Wingfield Manor, have their representatives in Lancashire; and the Blackshale coal is, with much reason, supposed to be the representative of the Royley, or Arley mine, of the same county.

For the purpose of affording a comparison of the formations towards the north and south of the field, I here select sections from Nottinghamshire, and Barnsley in Yorkshire.

GENERAL SECTION OF STRATA.

Nottinghamshire.*—(Shireoak Colliery.)

		Feet.
Permian Rocks	Upper Permian Marls and Sandstone	56
	Magnesian Limestone	102
	Lower Permian Sands and Shale	38
Strata, with beds of hæmatite and ironstone		42
The Manor Coal		2
Strata, with several thin coals		706
Shireoak or *Melton*, or *Baelbro' Hall Coal*		4¼
Strata, with an inferior coal, 3/2 thick		120
Furnace Coal		2¾
Strata		138
Hazles Coal		3
Strata		238
Top Hard Coal (or *Barnsley Coal*)		3¾
Strata, *Dunshill Coal*, 2¾, Strata		155
Waterloo Coal		2½
Strata, with two coals, 2 feet each in thickness		345
Soft Coal		3½
Strata		120
Lower Hard Coal		4
Strata, *Piper Coal*, 2¼, Strata		200
Furnace Coal		4
Strata, with Yard Coal		360

Barnsley, Yorkshire.†

	Feet.
Magnesian Limestone	75
Lower Permian Sandstone	54
Red Rock of Rotherham	?
Strata	0 to 100
Pontefract Rock	100
Strata	70
Ackworth Rock	54
Strata	510
Shafton Coal	5
Strata, principally sandstone (Chevit Rock)	393
Muck Coal	3½
Strata	219
Woodmoor Coal	3
Strata with Half-Yard Coal	45
Winter Coal	4
Strata.	
Beamshaw Coal	3
Strata, with Kent Coal 1 foot, and Maple Coal 4½ feet (inferior quality).	
Strata	216
Barnsley Coal	9¼
Strata	198
Swallow Wood Coal	3
Strata	234
Joan Coal	2
Strata	60
Flocton Top Coal	3¼
Strata	120
Park Gate Coal	5
Strata	78
Thorncliffe Thin Coal	2½
Strata	123
Four-Feet Coal (variable)	2½

* Partly taken from section of Shireoak Colliery by Messrs. Lancaster and Wright, "Journ. Geol. Soc.," vol. xvi, p. 138.

† Rev. W. Thorpe, "Section of Strata."—*Ibid.* I need scarcely observe that the thickness of the strata and coals is variable.

GENERAL SECTION OF STRATA—*continued.*

Nottinghamshire.—(Shireoak Colliery.)		Barnsley, Yorkshire.	
	Feet.		Feet.
Clod, or *Black Shale Coal*	...5 to 6	Strata	108
Strata	... 480	*Silkstone Coal*	5
Kilburn Coal	3½ to 5	Strata	195
Strata (with ironstone) ...	... 350	*Whinmoor*, or *Lowmoor Coal* ...	2½
		Strata ... ...(about)	150
		Flagstone ... ...(about)	36
Flagstone overlying the Lower Coal-measures consisting of flagstones, shales, and the coals with Gannister floors, thickness rather uncertain (about)	500	Strata, principally shales ...	495
		Halifax Coal (with *Pecten papyraceus* in the roof), and a floor of Gannister	1⅝
		Strata (shales and flags) ...	81
		Halifax Soft Coal	1½
		Strata	150
Millstone Grit.		Millstone Grit.	

The following is a section of the strata at Cinderhill Colliery, showing their character near the southern extremity of the coal-field: *—

VERTICAL SECTION OF THE NOTTINGHAM AND DERBYSHIRE COAL-FIELD.

The first part (to the Top Hard Coal) from a pit at Cinderhill.

No.	Description of Strata.	Thickness.		Depth.	
		Ft.	In.	Ft.	In.
1	Limestone (Magnesian)	5	4	—	
2	Light-blue and brown stone in beds	6	3	11	7
3	Blue-stone	8	5	20	0
4	Dark-pink bind	3	8	23	8
5	Dark-grey stone	0	4	24	0

* W. T. Aveline, "Geology of Nottingham," "Mem. Geol. Survey," 1861.

VERTICAL SECTION OF THE NOTTINGHAM AND DERBYSHIRE COAL-FIELD—*continued.*

No.	Description of Strata.	Thickness.		Depth.	
		Ft.	In.	Ft.	In.
6	Red stone with pebbles	1	0	25	0
7	Clunch (usually tough clay or shale)	1	9	26	9
8	Bind	19	0	45	9
9	Ironstone	0	3	46	0
10	Soft clunch	5	0	51	0
11	Black shale or bind	2	7	53	7
12	Clunch	6	8	60	3
13	Bind, with bands of ironstone	40	4	100	7
14	*Chillery Coal*	0	7	101	2½
15	Light and dark clunch	6	0	107	2½
16	Bind	20	9	127	11½
17	Ironstone	0	2	128	2
18	Bind	14	7	142	9
19	Soft Coal	1	2	143	10½
20	Shale bind and clunch	20	2	164	0½
21	*Soft Coal*	2	4	166	5
22	Clunch and bind, with bat and shale	18	10	185	0
23	Soft Coal	1	0	186	3
24	Clunch and bind	1	0	187	3
25	*Soft Coal*	1	8	188	10½
26	Clunch and stone	9	5	198	3½
27	Bind, clunch, stone, and bat, with a little coal and ironstone	81	8	280	0
28	*Coal*	3	6	283	6½
29	Dark clunch, with bat and ironstone	20	8	304	2½
30	Coal	0	7	304	9½
31	Shaly bind	10	1	314	10½
32	*Soft Coal*	2	4	317	2½
33	Shale and bind	36	2	353	4½
34	*Soft Coal*	3	4	356	8
35	Dark clunch, with impressions of plants	3	11	360	7½
36	*Soft Coal*	1	3	361	10½
37	Clunch and bind	45	3	407	1½
38	*Coal*	1	5	408	6½
39	Black shale and bind	29	7	438	1½
40	*Soft Coal*	2	5	440	6½
41	Shale clunch, etc.	68	7	509	1½
42	*Coal*	3	9	512	10½
43	Shale and bind and a few small beds of ironstone	82	3	595	1½
44	*Coal* (hard)	2	2	597	4
45	Clunch, bind, and shale	50	0½	647	4
46	*Main*, or *Top Hard Coal* (with clay partings) ...	8	2	655	6

The depths and thicknesses of the seams below the Top Hard Coal in the same district as given by Mr. Aveline are as follows:—

TOP HARD, OR RIFLER COAL.

—	Thickness.		Depth below Top, Hard.	
	Ft.	In.	Ft.	In.
Bind with ironstone...	25	2	—	
Coal	0	10	424	5
Clunch and bind	11	0	—	
Coal	0	10	436	3
Bat, clunch, and bind	9	9	—	
Coal (probably the Ell Coal)	1	0	447	0
Bind and rock	54	0	—	
Main, or *Deep Soft Coal*	3	0	504	0
Bat	1	0	—	
Dark clunch and fire-clay	12	6	—	
Bind and rock	6	10	—	
The Deep Hard Coal	3	6	527	10

The following section gives the chief coals below the Deep Hard Coal:—

—	Thickness.		Depth below Deep Hard.	
	Ft.	In.	Ft.	In.
Clunch, bind, etc.	66	0	—	
Piper Coal	5	0	71	0
Bind, clunch, and other strata	138	0	—	
Furnace Coal	4	0	213	0
Clunch, bind, etc.	108	0	—	
Yard Coal	3	0	324	0
Clunch, bind, etc.	30	0	—	
Black Shale Coal (Silkstone)	5	4	359	4
Clunch, bind, etc.	459	0	—	
Kilburn Coal	3	6	811	10
Depth of Kilburn Coal below Top Hard Coal ...	—		1,339	8

In Derbyshire the principal coals are the "Top hard" and "Lower hard" seams, producing the valuable splint-coal; the "Upper soft" and "Lower soft" coals; and in Yorkshire the most remarkable are the "Silkstone" and "Barnsley thick coals." The former is undoubtedly identical with the "Arley mine" of Lancashire; and thus this fine bed of coal, which seldom exceeds 5 feet in thickness, has originally spread over a tract embracing not less than 10,000 square miles!

Prof. Green states that the Silkstone Coal is perhaps the most highly prized of the Yorkshire seams. Where it occurs at its best it is bituminous, very pure, and has the highest reputation as a house coal. It occurs in two seams with a thin clay parting, and its thickness varies from 3 to 6 feet. North of Cawthorne it deteriorates in quality.*

The Barnsley Coal (known also as the Top Hard, Elsecar, and Gawthorpe Coal) is the great seam of the Yorkshire Coal-field. It derives its great value from the fact that a portion of the seam is semi-anthracitic, well adapted for use on locomotives, in steam-vessels, and for iron-smelting on account of its high heating power. The following is the analysis of the middle or hard portion of this seam at Lord Fitzwilliam's Elsecar Colliery †:—

Carbon 81·93, Hydrogen 4·85, Oxygen 8·58, Sulphur 0·91, Ash 2·46. The soft coal is sent to London, and only inferior portions are sold in the district.

The Upper and Lower Hard coals, and the Silkstone seam, produce that remarkably deep glossy coal with long fracture, known as "splint." Different seams have different qualities, and are suited for household, steam, or gas purposes.

* "Geol. Yorkshire Coal-field," p. 228.

† *Ibid.*, 382.

In the Lower Coal-measures, or Gannister beds, described originally by Prof. Phillips,* one or more of the coals, with their roofs of black shale filled with *Aviculo-pecten papyraceus*, *Goniatites*, *Posidonomya*, etc., can be identified with those which range over South Lancashire: all of which facts go to prove the original continuity of these great coal-fields.†

The following section, including a portion of the Middle and the whole of the Lower Coal-measures from the neighbourhood of Dewsbury and Halifax, will give a general view of the series as it occurs in the north-western portion of the coal-field: ‡—

Coal-series near Dewsbury and Halifax.

MIDDLE COAL-MEASURES.

—	Depth. From— Ft.	Depth. From— In.	Depth. To— Ft.	Depth. To— In.
Haigh Moor Coal	2	11	4	0
Measures, with Thornhill and Dewsbury Rocks	—		340	0
Joan, or *Parson's Coal*	1	3	2	3
Measures	—		58	0
Flockton Thick Coal, with partings (variable)	—		9	0
Measures	—		42	0
Flockton Thin Coal	1	5	3	0
Measures, with *Old Hards*, or *Dawgreen Coal* ...	—		100	0
Coal	—		1	1
Measures	—		68	0
Green Lane, or *Middleton Little Coal*	0	6	3	6
Measures	—		6	4
New Hards, or *Middleton Main Coal*	2	0	4	6
Measures	—		60	0
Wheatley Lime Coal	1	0	3	0
Measures	—		94	0
Blocking, or *Toftshaw Coal*	1	3	2	4

* Article, "Geology," in *Encyclopædia Metropolitana*.

† See Mr. Binney, "Trans. Geol. Soc.," Manchester, vol. ii, Part VII.

‡ Curtailed from "The Geology of Dewsbury," Expl. of Sheet 88, N.E., "Mem. Geol. Survey," by Messrs. Green, Dakyns, Wood, and Russell.

LOWER COAL-MEASURES, OR GANNISTER BEDS.

—	Depth.			
	From—		To—	
	Ft.	In.	Ft.	In.
Measures	—		89	0
Lonsey Coal, of Whitley and Hopton	0	5	2	8
Measures	—		78	0
Strata, with *Whinmoor Coal*	—		38	0
Sandstone, with "Oakenshaw Quarry Stone" ...	—		170	0
Yards, or *Crow Coal*	0	2	2	0
Measures, with *Ironstone* (worked at Low Moor)	—		36	0
Low Moor Black Bed Coal	1	4	3	0
Measures	—		119	0
Low Moor Better Bed Coal (very pure)	1	0	2	6
Fireclay	0	7	4	0
Measures, with Elland Flagstone	270	0	330	0
,, three thin coals (Yards, Band) ...	176	0	250	0
Halifax Hard Coal (*Gannister Coal*)	—		2	3
Measures	—		30	0
Middle Band Coal	—		0	10
Measures	—		60	0
Halifax Soft Coal	—		1	6
Measures	80	0	140	0
Thin Coal and Fireclay	1	0	7	0
Millstone Grit in several beds, with intervening shales.	—		—	

Over the northern portion of the coal-field, between Bradford and the valley of the Calder from Dewsbury to Brighouse, the strata are much broken up by faults, which makes it impossible to represent this tract on the small index map.

Fossil Remains.—These have been summed up by Mr. Denny as consisting of 17 species of fish (placoid and ganoid). Of molluscs, 5 cephalopods, 17 conchifers and brachiopods. Crustacea, *Cythere* (Cypris). In the roofing shale of several of the coal-beds fish remains occur, and so

plentifully in the case of one of these, at Middleton, that the miners call it the "fish-coal." In the roof of the "Halifax Coal," of the Lower Coal-measures, *Goniatites Listeri* is found throughout its entire course, sometimes beautifully preserved in iron pyrites, and with this is associated *Aviculo-pecten papyraceus.*

In the "Catherine Slack Coal" near Halifix, *Nautilus Rawsoni* and *Orthoceras Steinhaueri* are frequent.

In the Middle Coal-measures there are bands of iron-stone, filled, over a great extent of country, with *Anthracosia* (Unio) and *Cythere* (Cypris).

Extension of the Coal-field under the Permian and Triassic Formations.—Reserving to another page the full discussion of the question regarding the extent and form of the coal-field under the newer formations, I may here state that I share the opinion of those who consider it most probable that this great coal-field is really a basin, partially exposed, partially concealed; and that east of a line which may be drawn through Wakefield and Worksop in a direction N.N.W. and S.S.E., the strata may be expected to rise towards the east, and ultimately to terminate somewhere beneath the Lias of Lincolnshire. This axis will probably be found to pass a little east of Shireoak Colliery, where the dip of the coals is slightly eastward, and which is consequently situated to the west of the axis. Under this view of the subject it will be observed, on referring to the General Map, that there is a larger extent of coal-measures concealed than exposed at the surface.

The new "East to West" Railway, opened on the 19th November, 1896, from Chesterfield to Lincoln, will open out a large coal-district in Nottinghamshire, on the

estates of the Dukes of Portland and Newcastle, concealed beneath the Triassic strata.

The boring experiment in search of coal, which was carried out a few years ago at Scarle, near Lincoln, was calculated from its position to throw light upon the question of the extension of the coal-measures under the newer formations,—and, if present, of their relations to the other rocks,—but unfortunately, although Carboniferous strata were undoubtedly reached, the cores brought up are of so peculiar a character as to leave it uncertain to what portion of the Carboniferous formation they belong. They consist of beds of grey earthy limestone and shale, which might belong either to the Upper Coal-measures or to the Yoredale Beds lying at their base. The following is the section passed through at Scarle* :—

—	Depth.		Thickness.
	From—	To—	
	Feet.	Feet.	Feet.
1. Alluvial strata	1	10	10
2. Lower Lias clay and limestone...	10	75	65
3. Rhœtic Beds	75	141	66
4. New Red Marl and sandstone...	141	1,500	1,359
5. Permian Beds	1,500	1,900	400
6. Carboniferous strata	1,900	2,030	130

The Carboniferous beds (6) appear to have been in a nearly horizontal position, and the following is a description of them :—

* The recent boring at South Car, near Epworth, to a depth of 3,195 feet—which passes through the Barnsley Hard Coal at 3,181 feet—shows that the coal-field has a wide extension beyond the Trent (1894).

—	Depth.	Thickness.
	Feet.	Feet.
Carboniferous Beds—		
Grey grits with plants	—	—
Shales with bivalves (Anthracosia)	1,955	55
Bluish calcareous shales and earthy limestone...	2,020	65
Fine breccia	2,024	4
Chocolate-coloured hard clays	2,030	6

The temperature at 2,000 feet was 79° F., taken with one of Negretti's thermometers supplied by the late Prof. Everett. At a depth of 917 feet, a strong feeder of water was encountered in the Lower Keuper Sandstone, and a still stronger at 1,250 in the Bunter Sandstone, when the water rose 4 feet above the ground. This water unquestionably percolates from a distance of 10 or 12 miles underground.*

All along the edge of the escarpment of the Magnesian Limestone, and for a short distance beyond, in Notts and Derbyshire, as far north as Rotherham, the coal-seams are found to dip eastward, at a greater angle than the Limestone itself, which, with the Lower Red Sandstone, rests unconformably on the coal-measures. At Shireoak Colliery, the full thickness of 327 feet of the Permian beds was passed through in the shafts, which commence at the base of the New Red Sandstone. North of Wakefield, the beds generally tend to rise towards the north-east, near to, and under, the Magnesian Limestone; and in the centre of the

* This boring was commenced in 1873 by a local company, for the purpose of testing the presence of coal in the neighbourhood of Lincoln—Mr. J. T. Boot, of Mansfield, being the engineer—and was carried out by the Diamond Rock Boring Company.—"Minutes of Proc. Inst. C. E.," vol. xlix, Part III (1877).

coal-field, the Ackworth Rock (a red sandstone), which is an outlier, and is amongst the highest of the Carboniferous beds, represents the central position of the whole basin.* The views of Prof. Sir A. Ramsay, the Commissioner who has reported on this subject, are so important that I take the liberty of quoting the general summary of them in his own words :—

"It has been shown in the evidence that the Yorkshire, Derbyshire, and Nottinghamshire coal-fields probably lie in the form of a basin, the northern, southern, and eastern edges of which lie underneath the New Red Sandstone, Permian, and other Secondary strata. In the centre of this basin are the Ackworth and Rotherham rocks, forming the topmost beds of the coal-measures, about 3 miles west of the edge of the Magnesian Limestone. When the different subdivisions of the coal-measure strata are extended underneath the Permian and New Red beds, and carried round concentrically from south to north, the area of available coal-measures beneath the Permian and other overlying beds may be roughly estimated at about 900 square miles; this concealed portion of the coal-basin being approximately equal to the coal-field exposed at the surface. It is estimated that, exclusive of part of the Gannister beds, the whole of the important coals of the coal-field lie underneath the New Red Marl, etc., and even a small part of the lower Lias, at depths of 4,000 feet and under; for the gradual

* See Prof. Ramsay's views on this subject in the Report of the Coal-Commission, vol. i, pp. 136–8 (1871), in which the whole evidence is handled with great ability, and leads the Commissioner to adopt the view of the basin-like form of the coal-field. This view is also supported by Prof. A. H. Green, of the Yorkshire College of Science, Leeds (*ibid.*, vol. ii, p. 504), whose evidence is illustrated by a sketch-map.

increase of thickness due to the coming on of successive formations of Magnesian Limestone, New Red Sandstone, Red Marl, and Lias, is probably compensated for by the gradual rise of the eastern edge of the basin towards the base of the lowest formation overlying the coal-measures. If this assumption be correct, then deducting the amount given by the late Mr. Woodhouse as proved under the Permian formation, namely, 8,306,140,050 tons, there remain about 23,083,000,000 tons still further available, a great part of which will lie at depths under 3,000 feet. The following are the proportions :—

"Area east of the Permian escarpment :—

	Tons.
672 square miles, 40 feet coal	26,768,179,200
132 " 20 "	4,620,697,600
	31,388,876,800
Deduct proved under Permian beds	8,306,140,050
	23,082,736,750"*

Depth of the Top Hard Coal along eastern border.—As the Magnesian Limestone is everywhere unconformable to the underlying coal-measures, we find it resting indifferently on all the beds from the Millstone Grit, N.E. of Leeds, to the highest beds of the coal-measures opposite Barnsley. The depth of the Top Hard Coal will, therefore, everywhere vary, and the following are its proved or estimated depths at various points from north to south,† along the margin of the Limestone :—

1. East of Barnsley and the Ackworth Rock, to Top Hard Coal, 1,850 to 1,900 feet ; and to Silkstone Coal, 2,850 to 2,900 feet.

* This is the gross estimate, not the "available" net quantity after deductions.—See "Report," p. 31.

† "Coal Commission Report," vol. i, p. 137 (1871).

2. Under Bolsover, to Top Hard Coal, 900 to 950 feet; to Lower Hard Coal, 1,500 to 1,550 feet.
3. Opposite Torkard, to Top Hard Coal, 1,236 feet.
4. Opposite Kirkby Woodhouse, to Top Hard Coal, 700 to 750 feet.
5. Langwith Colliery, 5 miles north of Mansfield, to Top Hard Coal, 1,620 feet.*
6. At Peasley Colliery, near Mansfield, the Top Hard Coal has been reached at 1,545 feet.
7. Under Newstead Abbey, to Top Hard Coal, from 1,500 to 1,600 feet.
8. Under Felley Abbey, to Top Hard Coal, 800 feet.

Thickness of the Magnesian Limestone.—This formation increases in thickness northward partly by the swelling out of the strata, and partly by the appearance of new beds. The following estimates of thickness at several points have been prepared by Mr. Russell, of the Geological Survey:—

		Feet.
In the neighbourhood of Longhills, near Hucknall Torkard	about	100
Near Annesley	,,	120
Near Kirby Forest	,,	100
Near Warsop	,,	140
Near Shireoaks	,,	318
Near Doncaster	,,	360
At Custon Park	,,	262
At Byram Hall (4 miles N.E. of Pontefract) ...	,,	312

Resources.

In estimating the resources of this partially concealed coal-basin in 1870, the late Mr. J. T. Woodhouse, the Commissioner to whom the duty was entrusted, very properly divided his estimates under two heads; those belonging to the visible coal-field lying to the west of the escarpment of the Magnesian Limestone, and those belonging to the

* Communicated by Mr. J. T. Boot, Mining Engineer of Mansfield.

portion, estimated by Sir A. C. Ramsay at 900 square miles, and concealed by the Permian, Triassic, and Liassic formations, known as the concealed coal-field.* The quantities remaining unworked in the visible coal-field in 1870 were estimated at 24,441 millions of tons; and in the concealed coal-field to a depth of 4,000 feet from the surface, 23,082 millions, from which large deductions were made amounting to about one-third, leaving for future use 15,388 millions of tons, making a total of 39,829 millions.

In making the estimates for the Coal Commission of 1904, Mr. Arthur C. Briggs, the Commissioner entrusted with the calculations, adopted a different plan, and omitting the division of "visible" and "concealed" for the whole coal-field, has taken a purely geographical arrangement, treating the whole area under three heads:—(1) Those of West Yorkshire; (2) South Yorkshire; and (3) Nottinghamshire and Derbyshire. The result is that a comparison of resources, except as regards the total estimates in both cases, cannot be made; but these latter work out approximately so closely, allowance being made for the quantity of coal raised in the intervening period of 32 years, as to give confidence in their accuracy.

Mr. Briggs arranges the seams under three heads according to thickness, as follows:—

* The reasons for assuming the basin-shaped form of the Carboniferous strata underneath the newer formations to the eastward, which weighed with Sir A. Ramsay, are stated in a previous page, but they are still hypothetical, notwithstanding the advance of mining in the past 30 years.

1. *Percentages of Thickness of Seams in the Three Districts, and within a depth of 4,000 feet.*

—	12 to 15 inches and 15 to 18 inches.	18 to 24 inches.	24 inches and upwards.	Total.
West Yorkshire	877,095,700	1,880,871,300	5,609,418,641	8,367,385,641
South Yorkshire	382,727,375	1,338,545,100	9,049,348,279	10,770,620,754
Derbyshire and Nottinghamshire	102,706,900	2,240,750,700	5,017,267,500	7,360,725,100
Total	1,362,529,975	5,460,167,100	19,676,034,420	26,498,731,495
Percentage ..	5·2	20·6	74·2	100

The next table gives a summary of the quantities of coal in each district according to the qualities of the seams:—

2. *Quality of seams.*

Quality.	West Yorkshire.	South Yorkshire.	Derbyshire and Nottinghamshire.
	Tons.	Tons.	Tons.
House	1,811,429,521	2,451,158,743	1,653,190,940
Gas	395,819,016	2,349,602,969	374,244,692
Steam	143,334,943	701,006,670	835,352,651
Manufacturing	5,164,399,395	3,362,706,333	3,885,563,017
Coking	852,402,766	1,906,146,039	612,373,800
Total	8,367,385,641	10,770,620,754	7,360,725,100

The above tables show that the total available quantity of coal in the proved coal-field at the end of 1903 was 26,498,731,495 tons within a limit of 4,000 feet from the surface, which at the rate of production for that year,

52,383,810 tons, would last for a period of 509 years. But if we exclude seams under 3 feet in thickness, the supply would only last for 183 years.

The "proved coal-field" above named not only includes that portion west of the margin of the Magnesian Limestone, but a certain area under that formation.

It should be remembered, however, that there is a large quantity of coal lying at a greater depth than 4,000 feet, estimated by Messrs. Mammatt and Longbotham at a net quantity of 483,844,875 tons. The average number of workable coal-seams is 15, giving a thickness of 46 feet of coal.*

The produce of this coal-field has taken a great bound forward during the last twenty-five years, having increased from 12,497,100 tons in 1859, to 17,865,367 tons in 1869, and to 52,383,810 in 1903; the number of collieries has also increased from 559 to about 810 in the same period, and of these several are situated on the Magnesian Limestone.

* In estimating the quantity of coal in the concealed area, Prof. Kendall, of the Yorkshire College of Science, gave valuable assistance to the Commissioners.

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CHAPTER XXI.

GREAT NORTHERN COAL-FIELD OF DURHAM AND NORTHUMBERLAND.

THE general succession of the strata and their relative position over the area of this coal-field is similar to that of Yorkshire, so that one section will serve to illustrate the structure of both. I must therefore beg the reader to refer to the transverse section at the commencement of the last chapter (Fig. 16, p. 177).

The Great Northern Coal-field extends from Staindrop near the north bank of the Tees, on the south, to the mouth of the Coquet, where it enters Alnmouth Bay, on the north, the distance being nearly 50 miles. Its greatest diameter is near the centre, along the course of the Tyne, which forms the great highway for the export of coal to the London market.*

From the Coquet to the Tyne the North Sea forms the limits of the coal-field. South of this, the escarpment of the Lower Permian Sandstone and Magnesian Limestone forms the boundary at the surface; but the coal-measures underlie these newer rocks; and since Dr. William Smith,† first on theoretical grounds, and afterwards by actual

* I have calculated the area of this coal-field from Mr. W. Oliver's map in the "Mining Record" office. There are some interesting details in "Our Coal and our Coal-pits," published by Messrs. Longman.

† About half a century ago.

experiment, demonstrated the existence of the coal-field at Haswell, near Durham, both the Triassic and Permian formations have been perforated over a large area, especially at Seaham and Ryhope in Durham.

Form and Structure of the Coal-field.—Recent observations have tended to confirm the opinion, that the structure of this coal-field is that of a trough, or irregular basin, of which the longer axis lies in a north and south direction, stretching from the apex near the mouth of the Coquet, through North Seaton and Jarrow Collieries on the north of the Tyne, and through Monkwearmouth Colliery,* below the Magnesian Limestone to the south of that river.† The examination of the coast-sections north of the Tyne, the results of which are laid down on the Geological Survey maps by Mr. Howell, places it beyond question that the beds rise towards the north-east, or in the seaward direction. Nor is there any reason to suppose this to be a mere local uprising of the strata; on the contrary, it may be considered as the commencement of a normal arrangement, ultimately resulting in an easterly outcrop under the sea-bed itself.

The southern limits of the basin are also capable of being defined with tolerable accuracy. The Magnesian Limestone (which with the Lower Permian Sandstone has been pierced by several coal-shafts), rests unconformably on the coal-formation, and near Hartlepool some of the seams have been proved to rise towards the south, and terminate

* At this colliery the coal-seams descend to a depth of 2,268 feet below the surface.

† This view is supported by Sir A. C. Ramsay, and by Mr. H. H. Howell, of the Geological Survey, in his evidence before the Coal-Commission.—See "Report," vol. i, p. 138 (1871).

against the bottom of these newer rocks. The lowest workable coal-seam, called the "Brockwell" Coal, passes at its outcrop under the Magnesian Limestone immediately east of Shildon, dipping to the north-west at an angle of 15 to 18 degrees.* This then gives us the line of the southern margin, which Sir A. Ramsay considers may be drawn from Seaton Carew, north of the entrance to the Tees, westward to Middridge Grange, 4 miles south-east of Bishop Auckland. To the south of this line, the Permian and Triassic strata would be found to overlie only Millstone Grit and Yoredale rocks.†

The regularity of the basin-like form towards its southern margin is somewhat interrupted by the presence of a fault, known as the "Butterknowle Dyke," which ranges in a W.S.W. and E.N.E. direction, depressing the strata on the south to the extent of 700 feet, and bringing in the upper measures, with all the coal-seams from the "Five-quarter" downward, under the Permian rocks at Leasingthorne, Black Boy, and Eldon Collieries.‡ To the south of this fault the strata dip rapidly toward the N.N.W., thereby bringing the lowest seams in contact with the overlying Permian formation, and ultimately the Millstone Grit itself,

* Mr. Howell, Evidence, *supra cit.*

† Prof. Ramsay, *ibid.* Sir R. Murchison, in his address, delivered at Nottingham, has expressed a doubt of the extension of the coal-measures south of the Tees, where they were bored for at Middlesborough by Mr. Vaughan, to a depth of 1,313 feet. At the bottom of the bore-hole rock-salt was encountered, but even the Permian Magnesian Limestone had never been reached. See Sir R. Murchison, "On parts of England where Coal may or may not be looked for" ("Trans. Brit. Assoc.," Nottingham, 1866).

‡ Mr. H. H. Howell, quoted by Prof. Ramsay, "Report, Coal-Commission," vol. i, p. 139 (1871). See map, section, and description of the Northern Coal-field, by Mr. Dunn, "Trans. North of England Institute of Mining Engineers," vol. xii.

from its visible outcrop near Heighington, 8 miles north-west of Darlington.*

From below the coal-field of Durham and Northumberland the Lower Carboniferous Rocks rise towards the west and north into swelling moorlands, and ultimately into the mountainous tracts of the Pennine chain, attaining at Cross Fell a height of 2,930 feet.

General Series of Formations.†

		Feet
New Red Sandstone—Red Sandstone and conglomerate.		
Permian Rocks, Magnesian Limestone, 600 to 700 feet.	1. Upper Permian marls with gypsum ...	100
	2. Crystalline limestone, with *Schizodus Schlotheimi*, and *Mytilus septifer*.	
	3. Brecciated limestone (Tynemouth Cliff), lying on—	
	4. Fossiliferous limestone, with *Productus*, *Strophalosia*, *Athyris*, *Avicula*, *etc.*, and numerous Polyzoa.	
	5. Compact limestone, with similar fossils.	
	6. Marl slate, calcareous shales, and thin-bedded limestone, with fishes of the genera *Palæoniscus*, *Acrolepis*.	
	7. Yellow Sandstone.	
Upper Carboniferous.	Upper Red Sandstone, with gypseous marl, *Pinites*, *Brandlingi*, *Trigonocarpum*, *Sigillaria reniformis*, *Calamites approximatus*	200

* The late Sir George Elliot, "Report Coal-Commission," vol. i, p. 26 (1871). Further information regarding the position and thickness of the coal-seams will be found in Sir Lindsay Wood's report on the quantity of unworked coal in this coal-field; "Report Coal-Commission" (1904).

† From the works of Profs. Sedgwick and King,

		Feet.
Coal-measures, 2,030 feet.	1. Upper Series, with thin coals, and a band of ironstone, with *Anthracosia, Lingula Credneri, Leperditia inflata, Holoptychius Hibberti*	900
	2. Middle Series. From the "High Main Coal" to the "Brockwell Coal" ...	2,000
	3. Lower Coal-measures, with two beds of coal, between 2 and 3 feet thick with marine shells*	150
Millstone Grit	Coarse grits and shales	414
Yoredale Rocks or Bernician Series.†	Shale, with bands of limestone and thin coals	540
	Ten beds of limestone, parted by as many beds of shale, containing coal-seams in Northumberland, upwards of	1,120‡
Tuedian Series	Grits, conglomerates, shales, and limestones, etc., with plants and *Anodonta Jukesii*.‡	

Coal-seams.§—The most important coal in the Newcastle district is the "High main" or "Wallsend" seam. It is the highest important, and varies from 5 to 6 feet in thickness. It is traversed by the "90-fathom" dyke, and is persistent in its general character to its northern and western outcrop, but southward towards the valley of the Wear is split up into two seams by the intercalation of sandstone and shale.

The "Bensham" seam, 20 fathoms below the "High Main," is very variable in its qualities, but is often unworkable. It acquires its chief value towards the east, and is

* Discovered by Mr. G. A. Lebour, F.G.S. See "Nature," 23rd February, 1878.

† Prof. Phillips' "Manual of Geology," p. 163.

‡ For a list of the fossils of the Permian and Upper Coal-measures, see Mr. J. W. Kirkby, "Journ. Geol. Soc.," vol. xvi, p. 412.

§ For the details of the coal-seams, I am indebted to Mr. Dunn, late Inspector of Collieries.

worked extensively under the Magnesian Limestone at Sunderland. Its general thickness is 6 feet.

The "Low Main" seam is known to range from Widdrington on the north to Ferry Hill on the south, a distance of about 40 miles. This coal, south and west of Newcastle, is moderately soft, and excellent for household use and coking. But passing northwards its character changes; it becomes very hard and less gaseous, and constitutes the most important bed of steam-coal. Below these lie several other seams, which will become more extensively worked as the supply from the valuable beds above described becomes curtailed.

The following is a list of the general series of coal-seams, for which I am mainly indebted to Mr. Dunn:*—

Coal-series of Northumberland and Durham.

NEWCASTLE DISTRICT.

			Ft.	In.
Upper Series.	*Closing Hill Seam* ...		1	8
	Strata...		450	0
	Hebburn Fell Seam ...		2	8
	Strata...		250	0
	Five-quarter Seam ...		4	0
	Strata...		260	0
	Three-quarter (Black Close) *Seam*...		2	0
	Strata...	50 ft. to	180	0
1.	*High Main Coal* (Wallsend) ...		6	0
	Strata...	33 to	150	0
2.	*Metal Coal* ...		1	6
	Strata...		33	0
3.	*Stone Coal* ...		1	6
	Strata...	60 to	100	0

* I have also availed myself here and elsewhere of the information contained in Mr. G. A. Lebour's "Outlines of the Geology of Northumberland" (1878).

			Ft.	In.
4.	*Yard Coal*	variable	2	10
	Strata	... 60 to	100	0
5.	*Bensham Coal*	2 ft. 5 in. to	5	0
	Strata...	... ...	78	0
6.	*Five-quarter Coal*	... ...	3	0
	Strata...	... ...	48	0
7.	*Low Main*, or *Hutton Coal* ...	... ...	6	0
	Strata...	... 30 to	100	0
8.	*Crow Coal*	inconstant	2	10
	Strata...	... ...	24	0
9.	*Five-quarter Coal*	... ...	3	8
	Strata...	... ...	30	0
10.	*Ruler Coal*	... ...	1	10
	Strata...	... ...	96	0
11.	*Townley*, or *Harvey Coal*	... ...	3	1
	Strata...	... ...	42	0
12.	*Jetty*, or *Tilley Coal*	... ...	2	2
	Strata...	... ...	42	0
13.	*Stone Coal*	... ...	2	5
	Strata...	... ...	18	0
14.	*Five-quarter Coal*	... ...	3	4
	Strata...	.. ...	30	0
15.	*Three-quarter Coal*	... ..	2	6
	Strata...	... ...	54	0
16.	*Brockwell Coal*	... ...	2	11

The series below the Low Main Coal is taken at Blaydon and Wylam, as the coals have never yet been worked at Newcastle.

The Brockwell coal has been taken by the Geological Survey as the boundary between the Middle and the Lower Coal-measures or Gannister beds, which form a band underneath, with some thin coals and marine fossils, including *Aviculo-pecten papyraceus*, discovered recently by Mr. Lebour near Whittonstall.* The Millstone Grit

* "Geol. Magazine," March 1878.

follows, also containing some thin seams, but decreased in thickness and deficient in character; underneath which comes the great "Bernician Series," consisting of numerous beds of limestone, of grits, sandstones, shales, and beds of coal, in all about 2,500 feet in thickness, representing the Yoredale Beds of the North of England, and the Lower Coal-measures of Scotland. Some of the lowest beds of Limestone probably represent the Carboniferous Limestone formation of Derbyshire.*

The following is the series of coals in descending order, as given by Mr. Lebour,† belonging to the "Bernician Series," and underlying those in the above list:—

Middle and Lower Carboniferous Coals.

BERNICIAN SERIES.

1. *Little Limestone Coal*—in three seams, of which the "Rough" and "Licker" are the chief.
2. *Great Limestone Coal*—or Dryburn Coal, worked at Lowick.
3. *Shilbottle Coal*—below the "Six-Yard Limestone."
4. *Beadnell Coals*—below the Beadnell Limestone; in two seams, of which the lower reaches 6 feet.
5. *Oxford Limestone Coals*—below the Oxford Limestone, in four principal seams.
6. *Dunstone Coals*—below the Dun Limestone; in three seams.
7. *Blackhill Coal*—also called the "Little Howgate Coal."
8. *Hardy Coal*—sometimes in two seams.
9. *Bulman Coal*—5 fathoms below the last.
10. *Three-quarter Coal*—about 18 fathoms below the last.
11. *Cooper Eye Coal*—also known as the Stony Coal; 3 or 4 fathoms below the last.
12. *Wester Coal*—about 10 fathoms below the last.

* This point is more fully explained in my paper on the "Classification of the Carboniferous Series." "Quart. Journ. Geol. Soc.," November, 1877, p. 635.

† *Supra cit.*, p. 39.

Basaltic Dykes.—The coal-field is traversed by several narrow basaltic dykes, generally ranging a little south of east, and running for several miles in nearly straight lines. The beds of coal on approaching these dykes become anthracitic, and ultimately worthless. Mr. Lebour separates them into two sets, the first ranging nearly east and west, and the second N.E. and S.W. To the former are referable those of Hebburn, Cramlington, Bedlington, Lower Wansbeck, Acklington, Trobe's Dene, Beadnell, and Holy Island, or Lindisfarne, one of the largest in the country. Those of the second set are the Brunton, Bavington, Lewis Burn, Blackburn, Plashetts, Boulmer, Hampeth, Howick, and Cornhill. The Cock-field Fell dyke in South Durham ranges from W.N.W. to E.S.E. These dykes are newer than any of the strata with which they come in contact; they also cut across the faults; and from their resemblance both in composition and mode of behaviour to those which traverse the Carboniferous beds of Scotland, Sir A. Geikie has arrived at the conclusion that they are of the same Miocene age as those of the latter country.* Many of the above dykes have altered and baked the strata which they traverse, the coal being sometimes completely coked, or converted into cinder; at other times, however, their effects are less obvious. Besides the dykes which reach the surface, there are others which only burrow below, and in rare cases, some have been found to overflow, as in the case of the Acklington Dyke, where it approaches the Cheviot Hills. Other cases are known, which have been described by Sir J. Lothian Bell.† On the other hand, the upper limit of one of these dykes, where it bifurcates and

* "Trans. Brit. Assoc.," 1867, p. 51.

† "Proc. Roy. Soc.," vol. xxiii, p. 543.

terminates below a bed of Sandstone, is exposed to view on the coast a little south of Seaton Sluice.*

Faults.—One of the largest of these is the "Ninety-fathom Dyke" of Denton Colliery. Along its course the strata are depressed on the north side to the extent of 200 fathoms between Gosforth and Killingworth. Another important "Dyke" is the "Shublick," which runs across Northumberland into Cumberland, causing a high dip of the strata. Most of the east and west faults do not traverse the Magnesian Limestone, being of anterior age to its formation.

Coal under the Sea.—To what distance from the shore coal will be available, is a question which cannot be directly answered, as every seam presents the problem under a different aspect. Questions regarding depth, thickness, regularity, and absence of faults, as well as the nature of associated strata, are here presented in relation to the coal-seams themselves: and depth of sea-bottom in relation to the sea. In every case a considerable breadth of coal where it approaches the outcrop must necessarily be left as a barrier; and it is unquestionable, that faults traversing the strata under the sea, at a considerable depth and pressure of water, and especially if there are beds of porous sandstone overlying the coal-seams, would give facilities for the influx of sea-water into the mines so as to prevent, or impede, the working of the coal. Sir Lindsay Wood has taken 3 miles under the seas as the limit to which the coal-seams will be workable in his estimate of the quantities available for future work.

With reference to this special coal-field, the late Sir George Elliot considered that, in that portion of the dis-

* Lebour, *supra cit.*, p. 48.

trict south of the Tyne, a minimum distance of $3\frac{1}{2}$ miles may be included as available; and that it is possible that a much wider extent will ultimately be worked by means of shafts sunk below the sea itself at a distance from the shore;* on the other hand, the late Mr. Forster assumed a distance of only 2 miles in breadth along the coast for that part of the coal-field north of the Tyne. This difference of opinion, on the part of gentlemen of such experience in mining undertakings, is a sufficient proof that the question is at present involved in much uncertainty.

Resources (1903).

In estimating the extent of this coal-field, we must include not only the area of the visible tract of coal-measures beyond the limits of the Permian formation, but that also which is concealed beneath this formation, though now very nearly proved over its whole area. Along with this is included about 40 square miles of sea-covered coal-seams, of an aggregate of 23 in number.

The Commissioner appointed to report on the resources of this coal-field in 1901 was Sir Lindsay Wood, whose results are given in the following table:—

* "Report, Coal-Commission," vol. i, p. 26 (1871).

1. Area of visible coal-field, beyond the limits of the Permian and New Red Sandstone	460 square miles.
2. Area of concealed coal-field	225 „
3. Area under the sea supposed to be available ...	111 „
4. Number of workable seams from 12 inches upwards, 23, giving a thickness of available coal	from 46 to 60 feet.
5. Net available quantity of coal on land, after necessary deductions for loss, etc. (Northumberland)	2,567,923,681 tons.
6. Net available quantity under the sea	1,112,910,292 „
7. Net available quantity on land (Durham), including seams down to 12 inches in thickness	4,401,087,735 „
8. Quantity under the sea (Durham Coast), including a breadth of 3 miles, with an area of 61 square miles	870,028,611 „
Total...	**8,951,950,319** „

Lower Carboniferous Coals.—These have already been described under the head of the "Bernician Series," and Mr. Nicholas Wood,* in giving a full account of the coals of Northumberland, states that they are worked at Talkin, Tindal Fell, Fourstones, Acomb, and Fallowfield. A very interesting section of the series is tabulated by Mr. Hutton, from the Millstone Grit down to the "4-feet seam" of Tindal Fell, for which I must refer the reader to the memoir itself.†

The available quantity of coal in this district is estimated by Sir L. Wood (in 1903) at 1,523,750,000 tons as representing the quantity in the north-west of Northumberland outside the true coal-field, which, added to the

* "Trans. Nat. Hist. Soc., Northumberland," vol. i.

† *Ibid.*, vol. ii, p. 24.

former, gives a total available quantity from the Carboniferous rocks of this part of England :—*

	Tons.
1. Upper Carboniferous Coal	8,951,950,319
2. Lower Carboniferous Coal	1,523,750,000
Total	**10,475,700,319**

Notwithstanding that the Great Northern coal-field has been drawn upon more heavily than any other of the British coal-fields, and for a larger period, the produce has rapidly increased during the last quarter of a century. This is partly due to the creation, and prodigious expansion, of iron-manufacture along the estuary of the Tees, which has its centre in Middlesborough; and partly to the enormous demands from the metropolis of England.

In 1859, the produce of this coal-field was 16,001,125 tons from 183 collieries; in 1869, or 10 years later, the produce reached 25,765,430 tons from 297 collieries; and of this 4,959,647 tons were converted into coke, chiefly for iron-smelting. In 1903, the produce was 47,894,608 tons.†

Plainmeller Coal-fields.—High amongst the moors of Northumberland, about 4 miles south-east of Haltwistle, we find three little coal-fields lying along the side of a large east and west down-throw fault. They are formed

* In addition to the above large total, Sir L. Wood has made an estimate of the quantity of Lower Carboniferous Coal underlying the upper coal-field of Northumberland. I am unwillingly obliged to exclude this from the "available" amount. It is inconceivable to me that the thin and intermittent seams of the Carboniferous limestone can ever become available at such necessarily great depths, even if all the upper seams of the true coal-measures were worked out. They could only be reached by passing through a great thickness of non-productive Lower Carboniferous strata, at a cost below their value.

† "Mineral Statistics," for 1859, 1869, and 1878.

of true coal-measures with Gannister beds of slight thickness below, and these reposing on Millstone Grit. There are in all five coal seams, the lowest of which, "the Cannel seam," is included in the Gannister beds. The general dip of the beds is south, at a moderate angle, and on the south of the great fault the Yoredale Beds reach the surface.*

Having now concluded the description of the coal-fields of England and Wales, together with the estimates of their reserves in coal, it will be interesting to give the following table, showing the output by counties since the year of the preceding Coal-Commission of 1871.

* See 6-inch Geol. Survey Map of Northumberland, No. 92, by M D. Burn

TABLE

SHOWING OUTPUT OF COAL BY COUNTIES OF ENGLAND AND WALES FOR THE YEARS **1870, 1880, 1890, 1900–03.**

COUNTY.	1870.	1880.	1890.	1900.	1901.	1902.	1903.
ENGLAND.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Chester	929,150	681,000	677,656	699,451	570,216	438,672	436,550
Cumberland ...	1,408,235	1,680,841	1,740,413	2,022,327	2,108,360	2,179,703	2,207,476
Derby	5,102,267	7,903,834	10,455,974	15,245,367	14,908,269	15,521,420	15,148,023
Durham... ...	27,613,539	28,063,346	30,265,241	34,800,719	33,954,438	34,808,460	35,873,268
Gloucester ...	1,430,950	1,195,930	1,419,616	1,578,386	1,524,981	1,527,745	1,406,021
Lancaster ...	13,810,600	19,120,294	22,123,522	24,842,866	23,691,138	24,441,761	24,517,711
Leicester ...	647,341	1,063,382	1,455,910	2,106,443	2,011,470	2,074,458	2,076,435
Monmouth ...	4,364,342	5,039,549	6,895,410	9,818,829	9,598,407	10,175.461	10,671,432
Northumberland	—	6,850,162	9,446,035	11,514,521	11,272,005	11,619,072	12,021,340
Nottingham ...	2,017,372	4,432,393	6,861,976	8,626,177	8,198,267	8,656,570	8,703,025
Salop	1,343,300	905,000	693,146	780,420	754,858	773,765	781,599
Somerset ...	525,000	757,802	921,870	1,046,792	928,539	962,549	962,663
Stafford	13,230,062	12,305,800	13,773,629	14,227,076	13,126,975	13,386,563	13,037,439
Warwick ...	599,120	1,101,386	1,744,174	2,957,490	3,099,863	3,304,370	3,449,068
Westmoreland ...	—	1,950	1,182	940	898	972	1,033
Worcester ...	—	1,429,000	923,531	806,919	736,140	729,617	746,363
York	11,545,400	17,473,806	22,338,886	28,250,679	26,975,460	27,966,148	28,532,362
Total ...	84,566,678	110,005,475	131,738,171	159,325,402	153,460,284	158,567,306	160,571,808
WALES.							
Brecon	—	100,616	259,260	440,682	442,194	431,769	413,919
Carmarthen ...	—	625,933	762,032	1,333,800	1,417,427	1,571,613	1,631,749
Denbigh ...	2,329,030	1,650,406	2,221,497	2,447,092	2,398,776	2,588,203	2,612,380
Flint	—	778,909	754,149	662,523	677,203	584,915	571,756
Glamorgan ...	9,299,772	15,320,096	21,426,415	27,686,758	27,709,042	29,077,439	29,375,397
Pembroke ...	—	79,386	71,908	48,140	42,190	49,301	60,790
Total ...	11,628,802	18,555,346	25,495,261	32,618,995	32,686,832	34,303,240	34,665,991

CHAPTER XXII.

COAL-FIELDS OF SCOTLAND.

IT will be observed, on looking at a geological map of Scotland, that the series of formations of which that country is composed, are arranged in bands crossing the island from south-west to north-east; and, on the whole, parallel to the central range of the Grampian mountains.

The Carboniferous series of Scotland forms one of these bands, stretching from sea to sea, and occupying a depression between the southern slopes of the Grampians on the one side, and the indented flanks of the "Southern Uplands" on the other. These are composed of Old Red Sandstone and Silurian rocks, stretching from Kirkcudbrightshire to Berwick, of which the Lammermuir, Moorfoot, and Lead Hills form a part. The height of many of these hills is considerable. Merrick Hill reaches an elevation of 2,751 feet, Cairns-Muir-of-Deugh 2,597, Black Larg 2,890, and Black Hope Scar 2,136 feet.

The western margin of the Carboniferous area is washed by the Firth of Clyde, and the river itself drains a large tract of the great central coal-basin. The eastern limit is the North Sea on both shores of the Firth of Forth. The northern boundary line leaves the River Clyde east of Dumbarton, passing along the southern slopes of the Kilpatrick, Campsie, and Stirling Hills, and continuing by Kinross and Cupar, enters the sea at St. Andrew's Bay.

The southern boundary is much indented in some places, but ranges in a north-easterly direction from Girvan, on the Ayrshire coast, to Dunbar. Throughout the greater part of its course the line of junction between the Carboniferous and Older Palæozoic formations is a fault, with a downthrow to the north, which has been traced on the maps of the Geological Survey. The extreme length from the coast of Ayr to Fifeness is 94 miles, the average breadth 25 miles.

This great range of Carboniferous rocks is not all productive of coal; hence the coal-bearing series forms several distinct fields or "basins," separated either by physical barriers, as firths and rivers; or by the uprising of the Lower unproductive Carboniferous rocks, or Old Red Sandstone, where the coal-series has been swept away. These separate fields may be thus denominated:—1. The coal-field of the Clyde Basin. 2. Mid-Lothian and Haddington coal-field. 3. The Fifeshire coal-field. 4. The Clackmannan coal-field. 5. The Ayrshire coal-field. 6. The Lesmahago coal-field.

Geological Age of the Scottish Coal-fields.—While England and Wales have only one series of beds producing coal-seams of much value, Scotland, on the other hand, is blessed with two series. The Upper of these is on the same geological horizon as the true coal-measures of England lying above the Millstone Grit, while the Lower underlies this formation, and occupies the position of the Bernician series of Northumberland, and of the Yoredale Beds of the north and central portions of the country. These two coal-bearing formations are known as "the Upper Coal-measures," or "Flat Coal Series," and the "Lower Coal and Ironstone Series" of Scotland respec-

tively; the reason being, that as the former generally occupy the central portions of the basins, they are but slightly inclined, while the latter being more marginal, are generally highly inclined along their outcrop.

The appearance of coal-seams and beds of limestone in Durham and Northumberland lying between the Millstone Grit on the one hand, and the Derbyshire Limestone on the other, will have prepared the reader for the condition of things as he finds them in Scotland. The change may be briefly stated as consisting of the introduction towards the north of beds of limestone and coal in the "Yoredale series," and the concurrent splitting up and thinning out of the solid mass of the Carboniferous Limestone in the same direction. The Millstone Grit is also greatly reduced in thickness as compared with its development in Lancashire and Derbyshire; and the "Gannister Beds" are represented only by a few feet of strata. On the other hand, the Lower Coal and Ironstone series of Scotland are characterised by minerals of great value, consisting of ordinary coal, cannel, oil shale, black-band and clay-band ironstone, and limestone, all of which have largely contributed to the rise and progress of trade and manufactures in the central districts of that country.*

General succession of the Carboniferous series of the Centre of Scotland.

The whole of the Carboniferous rocks are divisible into four groups, which in Fifeshire, Haddingtonshire, and

* The general opinion is, that the Lower Coal-series of Scotland is in the position of the Carboniferous Limestone. From the above statement it will be seen that I do not concur in this view for reasons stated in my paper on "the Carboniferous Series"—"Quart. Journ. Geol. Soc.," No. 132, p. 633.

Berwickshire, repose conformably upon the Old Red Sandstone, which seems to graduate into the Lowest Carboniferous strata.

	Divisions.	English Equivalents.
Upper Coal-measures. 200 feet.	Red sandstones of Bothwell, Hamilton, etc., without coal-seams. This series in Ayrshire contains a seam of limestone with *Spirorbis*, and rests unconformably on the beds underneath.	Upper Coal measures of Manchester, etc.
Flat Coal-measures.	Sandstones, shales, fire-clays, and coal-beds, with fish-remains, *Anthracosia*, *Anthracomya*, etc.	Middle Coal-measures.
Lower Coal-measures.	Shales, etc., with the "slaty-band," ironstone, and marine shells, *Discina nitida*, *Axinus*, *Conularia*, etc.	Gannister Beds, etc.
Moorstone Rock, or *Roslin Sandstone.* 400 feet.	Thick-bedded reddish and yellowish sandstones, shales, etc., down to the Garnkirk limestone.	Millstone Grit.
Lower Coal and Ironstone Series.	Bands of limestone, shales, sandstones, coals, black-band ironstone, oil-shale, etc., fish and entomostraca.	Yoredale Beds (Bernician series).
Carboniferous Limestone Series.	Beds of limestone and shale, including the Roman Camp and Gilmerton limestone.	Carboniferous Limestone.
*Calciferous Sandstone Series.**	(*a*) The upper, yellow, and white freestones, shales and fresh-water limestones of Burdie House, etc. (*b*) Dull reddish sandstones, shales, and conglomerates.	Lower Limestone Shale (Tuedian series).

* Mr. R. Etheridge, jun., has shown that, notwithstanding the occasional occurrence of lacustrine beds (such as the "Burdie House Limestone"),

With the exception of the two uppermost divisions, and occasional beds of estuarine strata, the whole of the above series may be regarded as of marine origin, attaining a combined thickness of 8,000 or 9,000 feet. The beds are largely intermixed with rocks of plutonic and volcanic origin, and in Ayrshire are overlaid unconformably by representatives of the Permian system, which occupy a small tract near the centre of the coal-field.* With this general introduction, I now proceed to give some details regarding the individual coal-fields.

several beds with marine invertebrata occur throughout the series *b*, which may therefore be regarded as to a large extent of marine origin. See "Quart. Journ. Geol. Soc.," vol. xxxiv, p. 1.

* Messrs. A. and J. Geikie—"Explanation of Sheet 14" (Ayrshire), "Mem. Geol. Survey," p. 22.

CHAPTER XXIII.

COAL-FIELD OF THE CLYDE-BASIN.*

THIS Basin includes portions of Renfrewshire, Dumbartonshire, Stirlingshire, and nearly the whole of Lanarkshire; and is traversed throughout its whole length by the River Clyde, along whose banks, above Glasgow, fine sections of the strata are laid open. At the base of the whole series are the Lower Carboniferous Sandstones, which are overlaid by the higher beds of this division, and with which are associated great sheets of contemporaneous traps, ashes, and agglomerates, which form the general base of the coal-bearing strata of the district.

These volcanic rocks of the Lower Carboniferous period rise into terraced hills, both to the north and south of the Clyde Valley, stretching from Dumbarton to Stirling, by Kilpatrick and Campsie, and from Greenock, by Neilston, to the neighbourhood of Stonehouse, where, however, along the valley of the Avon, they are unconformably overlapped by the Carboniferous Limestone-series, which rests directly on the Old Red Sandstone. Towards the east, the Lanarkshire coal-field is separated from those of the

* Mr. James S Dixon, Commissioner in charge of the district containing the Scottish Coal bearing areas, has given descriptions of the individual coal-fields, together with details of the resources, mode of working, and distribution. "Report" (1904).

Lothians by the uprising of the Calciferous Sandstone-series, which in the district of Linlithgow attains a thickness of nearly 4,000 feet.

Trap Rocks.—Besides the great sheets of felstone, porphyrite, and melaphyre, which were poured out at the earlier stage of the Carboniferous period, the strata are invaded by other igneous rocks, referable to (at least) two periods. These occur as sheets of melaphyre and dolerite, which have been intruded amongst the coal-strata in a fluid or viscous state, and are frequently the cause of much loss or difficulty in mining operations.* These rocks are probably referable to the age of the Upper Carboniferous series themselves, or possibly of the Permian. In addition to these intrusive sheets, there are also vertical dykes of basalt and dolerite, which range in nearly east and west lines for miles through the strata, and have been referred, with much probability, by Sir A. Geikie, to the Miocene Tertiary period.† There are thus to be found amongst the Carboniferous rocks of the West of Scotland, plutonic or volcanic rocks, referable to (at least) three periods; the last of which was separated by a long lapse of geological time from the two which preceded it.

Coal-series.—The general succession of the coal-series in Lanarkshire is illustrated by a vertical section by Mr. Ralph Moore, of which, slightly altered, the following is a synopsis:—

* One of these sheets forms the prominent ridge on which the Glasgow Necropolis is situated, from which a noble view of the Clyde Valley and of the city of Glasgow, with its venerable cathedral, is to be obtained.

† Address to the Geol. Section of the British Association, Dundee, 1867.

Upper Series, 840 feet.*	*b.* Red Sandstones of Hamilton, Waddington, and Blantyre, slightly unconformable to the underlying strata (*a*), 200 feet. *a.* From the Upper Four-Feet Coal downwards, with 10 coal-seams from 2 feet and upwards in thickness, also with the "Palace Craig" and the "Airdrie" black-band ironstones.
Middle Series, 960 feet.	*b.* From the slaty black-band ironstone, down through *a.* The "Moorstone Rock," or Millstone Grit, to the Garnkirk limestone.
Lower Series, 2,200 feet.†	Six courses of marine limestone from the Garnkirk Bed downwards to that which overlies the Hurlet coal. Three courses of black-band ironstone, and several beds of valuable coal.

Mr. William Moor, in a valuable communication to the Philosophical Society of Glasgow, presents us with the following succession of the coal and iron beds of that part of the coal-field lying along the valley of the Clyde :—

* Mr. Dixon states that in the Hamilton district there are seven seams of coal in about 300 feet of strata, giving an aggregate of about 27 feet of workable coal favourably arranged for working.

† Along the southern margin of the coal-field, and beneath the great sheets of contemporaneous trap, there occurs a remarkable series of shales and earthy limestones, described by Mr. John Young under the name of the "Ballagan Beds." They are almost unfossiliferous, and may probably be regarded as a lake deposit. See J. Young, "Geology of the Campsie District," "Trans. Geol. Soc.," Glasgow, vol. i, p. 22.

Coal and Ironstone Series in the Valley of the Clyde.

—	Depth.	Thickness. From—		Thickness. To—	
	Fathoms.	Ft.	In.	Ft.	In.
Palace Craig Ironstone (impure)	42	—		—	
Upper Coal (good)	48	3	0	4	6
Ell Coal (good)	63	4	0	8	0
Pyotshaw Coal (splint) ... average	67	—		4	0
Main Coal (good, soft quality)	68	3	6	5	0
Humph Coal	76	—		1	8
Splint Coal (for iron smelting)	81	—		3	0
Sour Milk Coal (variable)	84	—		3	0
Mushet Black-Band Ironstone	103	—		1	4
Soft-Band Ironstone	106	—		1	8
Curly Band Ironstone	120	—		0	5
Virtue Well Coal	127	—		2	6
Bellside Ironstone	132	—		0	7
Calderbrae Ironstone	134	—		0	8
Kiltongue Coal (variable)	136	—		5	0
Drumgray or Coxrod Coal...	148	—		2	0
Slaty Black-Band Ironstone	203	—		4	6
Boghead Gas Coal (1 to 20 inches) ...	203	—		0	20
Possil Ironstone	447	—		1	0
Lesmahago Gas Coal	467	—		1	0
Govan Band Ironstone	502	—		1	0
Hurlet Coal	—	—		5	0

Rapid Exhaustion of the Upper Thick Seams.—According to the statement of Mr. G. W. McCreath, Mining Engineer, of Glasgow, it would appear that the upper thick seams are being rapidly worked out in the Lanarkshire area. These have been mined on the "pillar and room" method; and at present the output may be taken as not exceeding 20 per cent. of the whole; the remaining 80 per cent. consisting of the lower and thinner seams are worked on the

"long wall" system. The output of Lanarkshire in 1901 was 16,603,230 tons.*

Black-band Ironstones.—These valuable minerals occur chiefly in the Lower Coal and Ironstone series, the uppermost being the Airdrie band, discovered by David Musket about the beginning of last century. It is about 16 inches in thickness, but is nearly all wrought out.† The black-band ironstones, west of Glasgow, not unfrequently pass into coal-seams, the carbonaceous matter gradually replacing the argillaceous carbonate of iron; while less frequently they pass into clay-band ironstones.

Gas Coals.—A valuable, but thin, bed of cannel occurs to the west and south of Glasgow, amongst the upper beds of the Lower Coal-series, and is supposed with good reason to be identical with the Lesmahago Cannel, so valuable for the production of gas. Associated with the same series are occasional beds of oil-shale.

The Boghead Gas Coal is the most remarkable of all the "Parrot coals" of Scotland for the quantity of oil and solid paraffin which it is capable of producing. It is from 18 to 20 inches in thickness, resting on a floor of fire-clay with *Stigmaria ficoides*, and overlaid by oil-shales, and occasionally black-band ironstone, in which marine shells of the genera *Discina*, *Lingula*, *Conularia*, *Axinus*, with *Anthracoptera*, have been discovered.‡ Very little of this valuable bed now remains to be worked.

Dykes and Faults.—The Carboniferous district is traversed by several remarkable basaltic dykes, which range generally

* "Report, Minutes of Evidence," R.C.Com., vol. ii, p. 47.

† Mr. W. Grossart "On the Upper Coal-Measures of Lanarkshire," "Trans. Geol. Soc.," Glasgow, vol. iii.

‡ Mr. Grossart, *ibid.*, 107.

for miles through the country along east and west lines. They are seldom more than 50 feet wide, and traverse all formations except those of the Drift period. They sometimes coincide with faults in the strata, but in general are remarkably independent of any of the previously existing fractures, and are seldom diverted from their nearly rectilinear courses by changes in the nature of the rock. Amongst the most remarkable may be mentioned—1. That which passes by Carron, Denny, and traverses the Campsie Hills above Lennoxtown. 2. That which, commencing a little to the south-east of Linlithgow, ranges by Blackbraes to Kilsyth. 3. Another which ranges by Cumbercauld about a mile to the south of the preceding. 4. Another ranging by Torphichen and Cadder, which coincides with a line of fault having a downthrow to the south. And (5) another which ranges by Chryston, nearly parallel to the preceding. One of these dykes is remarkably well shown in the quarries near Bishopsbridge.* The principal faults range in a similar east and west direction.

The organic contents of the Carboniferous rocks of the Clyde Basin have been very ably determined by several geologists of the district, and the results published in the Transactions of the Glasgow Geological and Philosophical Societies. A brief summary is all that can be inserted here.

Upper Series.—This series, lying above the horizon of the Slaty-band Ironstone, is characterised by molluscs of the genera *Anthracosia*, *Anthracomya*, and *Anthracoptera*; with fish of the genera *Platysomus*, *Cœlacanthus*, *Palæoniscus*, *Rhizodus*, and *Megalichthys*, all of which may be either

* These dykes are clearly laid down on the maps of the Geological Survey, Sheets 30, 31, and 32.

fresh-water or brackish. But a fossiliferous band, full of undoubtedly marine genera, has recently been detected high up in this series, by Mr. Whyte Skipsey, in a position about 60 fathoms above the "Ell Coal" (see section above), taken from a colliery at Drumpeller, east of Glasgow. The following were identified: *Productus scabriculus, Discina nitida, Conularia quadrisulcata, Bellerophon Urii,* and fragments of pentagonal stems of a crinoid.* The occurrence of this marine band reminds us of a similar instance which I have already described in the case of the Lancashire coal-field.†

Lower Series.—The Carboniferous Limestone series is abundantly loaded with marine forms, of which a very full list is given by Mr. J. Young,‡ for the Campsie district, of which the following is a selection:—

Echinoderms.—Archæocidaris Urii, Actinocrinus.

Anelids.—Spirorbis carbonarius, Serpulites carbonarius.

Crustacea.—Bairdia Hisingeri, Beyrichia arcuata, Cythere ventricornis.

Polyzoa.—Ceriopora interporosa, Fenestella plebeia.

Brachiopoda.—Athyris ambigua, Chonetes Hardrensis, Crania quadrata, Discina nitida, Lingula mytiloides, L. squamiformis, Orthis Michelini, Productus aculeatus, P. cora, P. costatus, P. Martini, P. reticulatus, P. Youngianus, Rhynchonella pleurodon, Spirifera bisulcata, S. glabra, Strophomena deleta var. analoga, Terebratula hastata.

Lamellibranchs—Aviculo-pecten arenosus, A. fimbriatus, A. granosus, Pecten Sowerbii, Pteronites fluctuosus, Area reticulata, Cardiomorpha oblonga, Cypricardia cylindrica, Leda attenuata, Modiola elongata, Myalina crassa, Nucula lineata.

Gasteropods.—Dentalium priscum, Euomphalus acutus, E. pentangulatus, Macrocheilus acutus, Murchisonia striatula, Pleurotomaria monilifera, P. conica.

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* "Trans. Geol. Soc.," Glasgow, vol. ii, Part I, p. 52.

† See p. 206.

‡ *Ibid.*, vol. i, Part I, p. 53.

Heteropods.—Bellerophon decussatus, B. Oldhamii.

Cephalopods.—Cyrtoceras unguis, Goniatites excavatus, G. Gilbertsoni, G. Striatus, Nautilus biangulatus, N., Subsulcatus, Orthoceras attenuatum O. cinctum, O. undatum.

Fishes.—Amblypterus punctatus, Cladodus mirabilis, Cochliodus magnus, Helodus lævissimus, Megalichthys Hibberti, Palæoniscus Robsoni, Petalodus Hastingsiæ, Pœcilodus obliquus, Rhizodus Hibberti, Rhizodopsis minor.

CHAPTER XXIV.

COAL-FIELDS OF MID-LOTHIAN AND HADDINGTON.

THESE coal-fields consist of a double trough, the deeper of which lies in Edinburghshire on the west, and the shallower in Haddington on the east.

The western boundary is the Pentland Hills, along the base of which the Carboniferous strata plunge rapidly towards the centre of the trough. The axis of the trough lies nearly north and south, passing by Dalkeith. On approaching the Carberry ridge, the beds again rise and crop out, and the Roman Camp limestone forms a ridge dividing the two troughs. On the east of the Carberry ridge the lower coal-seams again roll in, and form the wide trough of Haddington, where the beds lie in a position not much removed from the horizontal, and having Tranent as a centre.

To the north of these troughs, the coal-seams strike out to sea, are overspread by the Firth of Forth, and reappear on the opposite coast of Fifeshire. The quantity of coal under the waters of the Forth at a less depth than 4,000 feet, is estimated by Mr. Dixon at 2,442,960,000 tons.

The thickness of the coal-series in the Lothians is, according to Mr. Milne, upwards of 1,000 fathoms, consisting of sandstone 286 fathoms, of shales 188, of limestone 27, of clay 12, and of coal 21 fathoms. There are

from 50 to 60 coal-seams of greater thickness than 1 foot, the thickest being 13 feet.

Mr. Howell, of the Geological Survey, arranges the coal-series into three groups, of which the total thickness is 3,150 feet. This does not include the Calciferous Sandstone series, which contains very little workable coal,* but is characterised by the presence of great beds and sheets of contemporaneous and intrusive trap, which are ably described by Messrs. Howell and Geikie.† The coal-measures are confined exclusively to the Mid-Lothian trough, and do not occur in Haddington. The faults generally range from east to west, transversely to the axis of the troughs.

The workable coal-area, as measured from the maps of the Geological Survey, is 64 square miles.

Coal-seams of Mid-Lothian.

(Taken from the centre of the trough near Dalkeith.)

COAL-MEASURES, 1,220 FEET.

	Ft.	In.
Sandstone and Shale	346	0
Clay Knowes Coal	3	6
Splint Coal	3	10
Beefie Coal	3	6
Jewell Coal	4	0
Coal	2	8
Cowpits Little Splint	2	2
,, Five-Feet	5	6
Glass Coal	2	0
Barrs Coal	4	0
Cowpits Three-Feet	3	0
,, Six-Feet...	4	6
Millstone Grit	340	0

* The Houston Coal—about 2 feet thick—of Linlithgowshire is one of the few workable seams.

† "The Geology of Edinburgh." ("Mem. Geol. Survey.")

LOWER COAL-SERIES, 1,590 FEET.

	Ft	In.
Cowden Deception Coal...	2	2
,, Cryne	2	6
,, Mavis	2	8
,, Great Seam	8	0
,, Diamond	2	7
,, Lilla Willie	5	1
,, Blackbird Seam	3	11
,, Coronation	3	10
,, Hard Splint	3	3
,, Smithy Coal	2	9
,, Bryant's Splint	5	8
,, Aleck's Coal	2	7
,, Coal	2	6
,, Little Splint	2	1
,, Coal	2	1
,, Parrot Seam	3	0
,, Chalkieside Lime Coal ...	3	0

The above include only coals of 2 feet and upward. There are altogether no less than 46 seams with an aggregate thickness of 122 feet of coal. There are also nine seams of ironstone of 2 inches and upward.

The principal coals are "the Great Seam," which has been traced from its outcrop at Gilmerton, under the valley of the Esk, over the Carberry ridge, to the valley of the Tyne, a distance of 12 miles. It extends from the flanks of the Lammermuir range northward to the sea. Below this, at a depth of 250 fathoms, is the "North Greens" coal which yields the "Parrot-coal," valuable for its gas.

The East Lothian Coal-field.—The area of this coal-field is about 30 square miles, and the strata of which it is composed belong exclusively to the Lower Coal and Ironstone series, the seams of coal and ironstone which are wrought in it being the equivalents of the "edge coals" of

Mid-Lothian, some of which can be individually identified. The following is the series as given by Mr. Howell :*—

Coal-series of East Lothian.

	Ft.	In.
Coal "Great Seam"	7	0
Strata	50	0
Splint Coal	4	0
Strata ... ... from 7-ft. to	18	0
Parrot Coal	1	8
Strata ... ... from 7-ft. to	34	0
Three-Foot Coal	2	6
Strata	9	0
Four-Foot Coal ... from 3-ft. 8-in. to	4	11
Strata	118	0
Five-Foot Coal...	4	0
Strata, with Black-Band Ironstone ... about	130	0
Panwood Coal	1	6
Strata	72	0
Splint and Rough Coals (16 feet apart) ...	4	0
Strata	100	0
Haughielin Coals (sometimes "Parrot" Coal) ... ... 16-in. to	1	6
Strata	35	0

Lower Limestone Group.—The basis of the above series is the Lower Limestone group, consisting of three principal beds of limestone, separated by intervening strata of sandstone and shale, with one seam of coal of about 1 foot in thickness. These three limestones form a broad zone encircling the East Lothian coal-field on the east and S.E., and dividing it from the Mid-Lothian coal-trough on the west.

* "Geology of the East Lothian Coal-field," Messrs. Howell, Geikie, and Young, "Mem. Geol. Survey," 1866.

Underneath these occur the Calciferous Sandstones, with beds of volcanic ashes and contemporaneous igneous rocks, and also including the celebrated Burdie House, or Queensferry, Limestone, remarkable for the varied character of its fauna, which includes numerous genera of fish, small crustacea, and plants.*

* For a list of fossils of the Burdie House Limestone, see "Geology of Edinburgh," "Mem. Geol. Survey," p. 37.

CHAPTER XXV.

FIFESHIRE COAL-FIELD.

THIS coal-field is of considerable extent and of great mineral productiveness, but is over a large part of its eastern area much dislocated by faults, and damaged by the intrusion of igneous rocks. Nearly the whole of the coal-seams enter the sea between Kirkcaldy and East Wemyss, and present the following section as given by Mr. Landale in his valuable memoir:*—

Coal-seams of Fifeshire.

		Ft.	In.
1.	Parrot Seam	2	6
2.	Pilkembare Coal ...	2	0
3.	Wall	3	0
4.	Barn Craig	5	6
5.	Upper Coxtool Coal ...	3	0
6.	Lower ,, ...	3	6
7.	Den Coal	2	2
8.	Main or Chemis... ...	9	0
9.	Bush Coal	3	6
10.	Parrot ,, ...	2	3
11.	Wood ,, ...	3	0
12.	Earl's Parrot Coal ...	2	0
13.	Bowhouse ,, ...	6	6
14.	Brankston ,, ...	4	0
15.	Coal More ,, ...	2	6
16.	Coal Mangey ,, ...	2	6
17.	Boreland Coal... ...	3	6
18.	Sand Well Coal ...	3	0
19.	Dysart Main Seam ...	21	0
20.	Dysart Lower Seam ...	7	0
21.	Dunniker Five-Feet Coal	2	6
22.	Four-Feet Coal ...	4	0
23.	Three-Feet ,, ...	3	0
24.	Black and Parrot Coal	5	3
25.	Upper Smithy ...	3	0
26.	Lower ,, ...	1	6
27.	Parrot Seam Coal ...	2	0
28.	Coal Seam	2	4
29.	Invertiel Coal... ...	5	6
	Total thickness ...	120	6

The Invertiel coal overlies a thick and very constant bed of limestone which forms the physical base of the coal-producing strata. Underneath this limestone is a thick series of Lower Carboniferous rocks, the coal-seams of which are not of economical value, but which give evidence

* "Transactions of the Highland Society," vol. xii.

of volcanic activity throughout a period ranging from the Calciferous Sandstone up through the Carboniferous Limestone. The necks of many of the old submarine volcanoes which poured forth molten lava over the sea-bed, or vomited forth showers of ashes, stones, and blocks, can even now be identified, and appear as isolated bosses of basalt, tuff, and agglomerate ; as some of these invade the coal-measures of Fifeshire, it is not improbable they are referable to the Permian period.*

This coal-field contains excellent coal for gas, steam, and iron-smelting purposes, together with smithy coal, and some anthracite.

Clackmannan Coal-field.

This coal-field is separated from that of Fife by the uprising of the Lower Carboniferous rocks near Dunfermline. It stretches along the northern and eastern banks of the river Forth, by which it is separated from the great central coal-field of the Clyde Basin.

According to Mr. Geddes the southern portion of this coal-field is much exhausted ; the middle area is extensively worked, the northern portion is comparatively entire north of the river Devon ; these three divisions are separated by considerable faults. The following is the series of the coals in descending order at Old Sauchie :†—

	Ft.	In.		Ft.	In.
1. Coal	2	6	7. Mosie Coal	2	0
2. Three-Feet Coal ...	3	0	8. Lower Five-Feet Coal...	5	0
3. Upper Five-Feet Coal...	5	0	9. Splint Coal	2	9
4. Four-Feet Coal ...	4	0	10. Coalsnaughton	4	6
5. Nine-Feet Coal ...	9	0			
6. M'Nish Coal	2	9	Thickness ...	40	6

* Sir A. Geikie, "Address Brit. Assoc.," Dundee, 1867.

† Mr. Geddes, "Coal-Commission Report," vol. i, p. 76 (1871).

CHAPTER XXVI.

AYRSHIRE COAL-FIELD.

THE Ayrshire coal-field stretches along the coast from Ardrossan to the mouth of the river Doon, and extends inwards to the base of the hills of trappean rocks, by which it is separated from the coal-field of the Clyde Basin. It is a rich and productive district, large quantities of coal being shipped from Ayr, Troon, Irvine, and Ardrossan.

The Carboniferous rocks rest unconformably on the older formations, while they are in turn overlaid uncomformably by rocks of Permian age; in consequence of this, the true base and upper limit of the series can nowhere be seen.* The following is the general succession of the beds in descending order:—

GROUPS OF STRATA.	LOCALITIES.
Coal-measures.—(*b*) Red sandstones, fireclays and marls, with Carboniferous plants, and a seam of limestone, with *Spirorbis*. No workable coals. (*a*) A thick series of white and grey sandstones, dark shales, fireclays, ironstones, and coal-seams.	Monkton, Aunbank, Coylton Water below Coylton, Ravines of the Ayr at Catrine, Coal-fields of Ayr, Coylton, Dalmellington, Cumnock, Auchenleck, Lugar, and Sorn.

* "Ayrshire (Southern District)," "Mem. Geol. Survey of Scotland" (1869), p. 15.

GROUPS OF STRATA.	LOCALITIES.
Lower Coal and Ironstone Series.—Sandstones, shales, and limestones, with seams of coal and ironstone.*	Girvan Coal-field, Craigs of Kyle, Kiers, Sorn, etc.
Calciferous Sandstone Series.—Upper beds of white sandstones, cement stones and marls, below which are red sandstones, marls, and cornstones.	Dailly, the coast from the mouth of the Doon to Brackenbrae.

The following is the order of succession and average thickness of the principal coals in the Ayr district:—

Red Sandstone Series Overlying.

		Ft.	In.
Light sandstones, shales, fireclays, and thin coal	60 ft. to	70	0
Ell Coal		3	4
Strata		78	0
Crawfordston Coal		8	0
Strata	30 ft. to	60	0
Ayr, Soft, or *Five-Feet Coal*	...5 ft. to	7	0
Strata		150	0
Ayr, Hard, or *Splint Coal*		4	0
Strata		300	0
Black-Band Ironstone...		1	0
Strata		120	0
Uppermost Limestone		10	0

In the Dalmellington coal-field we find the following series:—

* In the south of Ayrshire this series is but poorly represented, but northward it thickens out, and produces several seams of workable coal. The Dalry black-band ironstone belongs to this part of the series.—Mr. J. Geikie, "Carboniferous Formation of Scotland," p. 12.

	Ft.	In.
Craigmack Black-band Ironstone ...	0	10
Strata	282	0
Lillyhole Coal	5	6
Strata	350	0
Chalmerston Coal	4	0
Strata	60	0
Minnevey Coal	3	6
Strata*	654	0
Burnfoot Black-Band	2	3

Igneous Rocks.—Besides the great beds of contemporaneous felstones, porphyrites, and melaphyres with volcanic ashes of the Lower Carboniferous period, which rise into the Dunlop Hills, and separate the Ayrshire coal-field from that of the Clyde Basin, there are frequent intrusive sheets and vertical dykes of dolerite and basalt, which have destroyed much of the valuable minerals, and greatly interfere with the successful prosecution of mining operations. The Permian rocks which overlie the coal-measures near the centre of the coal-field, are also underlaid by beds of porphyrite, melaphyre, and tuffs, which are referable, according to the views of the Government Surveyors, to the Permian period itself.

Sanquhar Coal-basin.—A small detached coal-field lies along the valley of the Nith for a distance of 5 miles, near the centre of which is the village of Kirkconnel. Along the N.E. and N.W. it is bounded by faults, bringing to the surface the Silurian Grits and Old Red Sandstone; in the opposite directions the coal-measures rest directly upon the Lower Silurian beds, the Lower Carboniferous series being absent.†

* In these beds, Mr. Geddes mentions the "Sloanston," "Camlarg," and "New" Coals, all of which are 3 feet and upwards in thickness.

† Map of the Geol. Survey, Sheet 15.

It contains several seams of coal, which are as follows:—

*Coal Seams.**

	Ft.	In.
Upper, or Creepy Coal	2	8
Main Coal	3	6
Wee ,, ...	1	10
Dauch ,, ...	3	8
Drumbowie Coal	4	9
New Coal	1	0
Total	18	3

* As stated by Mr. Geddes. "Rep. Coal-Commission," vol. i, p. 75 (1871).

CHAPTER XXVII.

OTHER COAL-FIELDS OF SCOTLAND.

Lesmahago Coal-Basin.

TO the south of the general tract of the Lanarkshire coal-field lies the detached basin of Lesmahago and Douglas, consisting of Carboniferous rocks resting unconformably upon, and nearly surrounded by, beds of the Lower Old Red Sandstone. The strata themselves belong to the Lower Coal-series, and are distributed along the valleys of the Nethan and the Ayre. The celebrated gas coal is considered to be on the same geological horizon as that of the western vicinity of Glasgow, which is known to lie well down in the same series. The following are sections of the strata curtailed from those of Dr. Slimon :—*

* From Appendix to Sir R. Murchison's paper on the "Lesmahago Silurians," in "Journ. Geol. Soc.," vol. xii, p. 25. The geological features of this district are also described by Mr. Geikie, "On the Old Red Sandstone of the south of Scotland," *ibid.*, vol. xvi, p. 314.

SECTION AT COAL BURN.

	Ft.	In.
Shale and limestone ...	10	0
Sandstone and shale ...	27	0
Gas and Dross Coal ...	1	0
Sandstones and shales ...	25	0
Dross Coal	3	0
Fire-clay	0	11
Dross Coal, with 6 inches of Horn Coal	3	11
Strata	13	0
Coal	3	0
Fire-clay	3	6
Coal	2	9
Strata	12	0
Black-Band Ironstone ...	0	8
Shales with ironstone ...	7	4
Smithy Coal	1	6
Fire-clay	1	6
Coal	4	0
Stone	0	7
Coal	4	7
Shales, with seams of ironstone	81	8
Coal, with 6 inches of stone	6	0
Strata, with ironstone ...	54	0
Coal (stinking)	5	0
Sandstones and shales ...	34	0
Limestone	1	8
Grey shale	20	0
Ironstone	0	8
Shale and limestone with *Productus*	46	0
Sandstone and limestone resting on Upper Old Red Sandstone	—	

SECTION AT AUCHENHEATH.

	Ft.	In.
Shales and sandstones ...	—	
Limestone	1	6
Shale	10	0
Strata, with four beds of limestone	225	3
Smithy Coal	1	4
Shelly clay	1	6
Coal	4	0
Strata	15	0
Gas Coal	0	10
Black-Band Ironstone ...	0	5
Shales with ironstone balls	3	8
Coal	0	8
Fire-clay	1	6
Dross Coal	3	0
Shales and sandstones ...	54	6
Coal	0	10
Shale	5	0
Gas Coal	1	9
Ironstone	0	4
Fire-clay	1	3
Coal	0	6
Sandstone resting upon limestone	—	

These beds are supposed to rest upon Old Red Sandstone.

This coal-tract is about $7\frac{1}{2}$ miles from east to west, and from north to south. Mr. J. Ferguson states that three-fourths of its area is stored with coal of second class quality. The once valuable "gas-coal" is said to be almost exhausted. There is at Ponfrich an aggregate thickness of 53 feet within a vertical depth of 200 fathoms.

CANOBIE COAL-FIELD, DUMFRIESSHIRE.

The small but valuable tract of Carboniferous rocks known as "the Canobie Coal-field," lies in the depression formed by Eskdale and Liddesdale, on the borders of the Cheviots. The beds repose on those of Lower Carboniferous age, and are overlaid by others of Permian age; and along the N.W. and S.E. the coal-field is bounded by faults. The general dip of the strata is southwards, and it seems not improbable that the coal strata are but the northern outcrop of a more extensive tract which lies concealed beneath newer formations towards the head of the Solway Firth.*

The following are the coal-seams of the Canobie district:—

Canobie.

	Ft.	In.
Three-Feet Coal	3	4
Six-Feet ,, ...	6	0
Nine-Feet ,, ...	9	0
Steam ,, ...	3	0
Five-Feet ,, ...	5	0
Blast-Top ,, ...	4	6
Seven-Feet ,, ...	6	0
Total	36	10

Mr. Geddes states that the 3-feet and 6-feet seams of Canobie are already exhausted; but considers that the Byreburn coals may be expected to underlie those of Canobie, in which case 14 millions of tons would be added to the known supply.

Argyleshire.—The parish of Campbelton contains a little coal-field, situated amongst metamorphic schists. For nearly a century coal has been worked on a limited scale,

* "Coal-Commission Report," vol. i, p. 77 (1871).

and, according to Mr. Geddes, three seams are known at Drumlemble, viz.: three, cannel or gas coal, from 18 to 30 inches in thickness; two, the main coal, 4 to 6 feet; one, underfoot coal, from 2 to 3 feet. Other seams may possibly exist in that district.

BRORA COAL-FIELD, SUTHERLANDSHIRE.

A small coal-field occurs at Brora, near the shores of Dornoch Firth. It has been shown by Sir R. Murchison to be of the age of the Lower Oolite, and in all probability contemporaneous with the carbonaceous strata of Whitby, in Yorkshire.* The following is part of the section of one of the pits from which the coal was formerly extracted :—

	Ft.	In.
13. Dark argillaceous schistus, with soft partings and a few shells	36	6
14. Very large-grained sandstone, with shells and wood (coal-roof)	5	0
15. Fine cubical coal, burning to white ash	3	8
16. Bituminous shale, containing natural oil; burns, but does not consume	2	0
17. Slate-coal with pyrites	1	4
18. Fire-clay and argillaceous schistus	90	0

The coal-bed appears to be at, or near, the base of the Great Oolite, as in Yorkshire; but the Inferior Oolite would appear to be absent, if the thick bed of shale belongs (as is probable) to the Upper Lias. The shells enumerated by Sir R. Murchison from the beds above the coal, are typical of the formations from the Great Oolite to the Calcareous Grit.

* "Trans. Geol. Soc.," London, vol. ii, 2nd Series, p. 393.

TABLE.

OUTPUT of Coal in Scotland, arranged in Counties, for the Years 1870, 1900, to 1903 inclusive.

COUNTY.	1870.	1900.	1901.	1902.	1903.
	Tons.	Tons.	Tons.	Tons.	Tons.
Argyll (including Dumfries)	95,474	155,589	127,939	154,565	158,595
Ayr	2,870,816	4,042,509	4,046,278	4,044,876	4,025,647
Clackmannan	196,086	424,696	429,836	426,808	405,376
Dumbarton	161,554	535,981	501,139	503,185	503,877
Dumfries (included with Argyll) ...	—	—	—	—	—
Edinburgh	492,513	1,329,495	1,364,399	1,438,821	1,623,390
Fife	1,387,933	5,419,373	5,601,501	6,134,171	6,376,985
Haddington	182,284	464,755	467,225	505,818	567,265
Kinross	—	38,762	22,528	72,348	130,833
Lanark	8,145,233	17,174,247	16,603,230	17,049,234	17,350,382
Linlithgow	405,119	1,184,092	1,316,570	1,434,707	1,537,056
Peebles	—	650	900	920	700
Perth	—	—	—	—	—
Renfrew	162,597	13,104	2,346	2,662	8,741
Stirling	832,933	2,322,676	2,306,880	2,342,152	2,298,737
Sutherland	2,011	6,175	5,739	5,042	4,656
Total	14,934,553	33,112,104	32,796,510	34,115,309	34,992,240

From the above table, it will be seen that the output of coal in Scotland has more than doubled since the Report of the first Coal-Commission in 1871.

The first pit was opened in 1598 by the Countess of Sutherland. That formerly in use was sunk in 1814, and up to the year 1827 70 millions of tons of coal had been raised. The works were discontinued in 1832.

*Resources of the Coal-fields of Scotland.**

The estimates of the available quantity of coal in the coal-fields of Scotland was drawn up for the Royal Coal-Commission of 1871 by Mr. John Geddes, one of the commissioners; and to no one could the task have been more worthily entrusted, as Mr. Geddes' long experience as a mineral engineer had given him opportunities of becoming acquainted with the details of the Scottish coal-fields, which were of the highest value to this inquiry. The estimate produced by Mr. Geddes of the coal-resources is, I find, much below that arrived at by myself in 1858; but for the Commission of 1904, the task was entrusted to equally competent hands, namely, those of Mr. James S. Dixon, one of the commissioners, who has considerably augmented the estimate of his predecessor.

Distributing the coal-fields into counties, Mr. Dixon gives the following quantities of available coal for each, the whole being included within a vertical limit of 4,000 feet (quantities below 1,000 tons are omitted) :—

* A valuable paper on "The Probable Duration of the Scottish Coal-fields" was read before the Mining Institute of Scotland at Kilmarnock on December 9th, 1899, by Mr. R. W. Dron, in which he estimates that all the proven coal in Scotland will be exhausted by the end of this century, and the reserve coal by the year 2086 at the present rate of increase of consumption.

County.	Available coal in millions of tons.
1. Edinburgh, west of the Pentlands	63,471
2. Lanark	2,604,515
3. Fife and Kinross	3,742,336
4. East Lothian	2,520,311
5. Dumfries	453,575
6. West Lothian	63,471
7. Stirling	1,316,742
8. Firth of Forth	2,442,960
9. Linlithgow	574,835
10. Ayrshire	1,082,547
11. Clackmannan and Perth	443,800
12. Dumbarton	247,897
13. Renfrew	111,385
14. Argyle	76,077
15. Sutherland	1,000
Total	**15,681,450**

It will be observed that Mr. Dixon includes a large quantity of workable coal, as available below the bed of the Firth of Forth; this view is corroborated by the experience of Mr. H. M. Cadell, who is actually working coal beneath the surface of the waters at Bridgeness. It appears that there is a thick deposit of silt and boulder clay overspreading the bed of the Firth, which acts as a waterproof cover to the coal-bearing strata, and enables mining to be carried on to a considerable extent with safety. This may be so as long as the cover remains intact; but should the water break in under pressure, I fear there would be great difficulty in draining the mine where the old workings were invaded. Mr. Cadell's coal is worked on the "long-wall" system between 400 and 500 feet below the bed of the sea.*

* "Trans. Fed. Inst. M. E.," January, 1898, p. 237, extract from "Iron and Coal Trades Review," September 17, 1897.

On comparing the above total quantity with that of the Report of the Commission of 1871, as drawn up by the late Mr. Geddes, amounting to 9,843,465,000 tons, it will be seen that, notwithstanding the large quantity raised in the intervening 33 years, there is a great increase in the estimate for 1903. This is accounted for to some extent by the fact that Mr. Dixon's estimates include seams down to 4,000 feet, as against 3,000 feet by Mr. Geddes; and also by the great amount of exploratory work, revealing the existence of coal in new districts, which has been carried out in recent years. In any case, for great depths, the quantity of coal between 12 and 15 inches in thickness amounting to 9·3 per cent. of the whole, may be considered valueless.

CHAPTER XXVIII.

CARBONIFEROUS ROCKS OF IRELAND.

A LARGE portion of the centre and S.W. of Ireland is occupied by Carboniferous Limestone, upon which at intervals repose higher strata productive of coal, and forming isolated coal-fields. The existence of these "outliers," as well as analogy with British geology, leads to the conclusion that, at the close of the Carboniferous Period, large tracts of coal-bearing strata existed over Ireland, which have since, to a great extent, been removed by denudation.*

Anthraxiferous and Bituminous Districts.—If we group the coal-fields south of a central line drawn from Galway Bay to Dublin Bay, into one series, and those north of this line into another, we have the following specialities in reference to each.

1. *The Southern Group.*—All the coal in the district of this group is anthracite, and this statement is true with reference to the coal of Clare, Limerick, Cork, Tipperary, Queen's County, Kilkenny, and Carlow.

2. *The Northern Group.*—On the other hand, the coal in this district is bituminous ; and this statement holds good with respect to the Arigna (Connaught), Tyrone, and

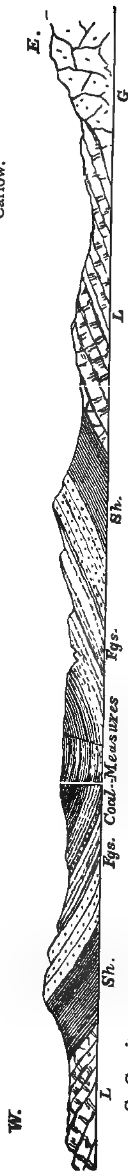
* On this subject, see the Author's "Physical Geography and Geology of Ireland," 2nd edit. (1878).

Ballycastle coal-fields ; while the general succession of the strata above the Carboniferous Limestone bears a closer analogy to that of England than in the case of the southern coal-districts.

SOUTHERN DISTRICT.

General Succession of the Beds.

The general succession of the strata is similar over this whole region, which has been surveyed and described by the Government Surveyors.* Upon a general basis of Carboniferous Limestone, there reposes a series of dark fossiliferous shales, which are overlaid by flagstones, upon which rest shales and sandstones with beds of coal. The shales and flagstones which rest upon the Limestone, I regard as the representatives of the Yoredale beds and Millstone Grit of England; and the overlying coal-measures as the equivalents of the Lower, and a part of the Middle, Coal-measures of the same country.† This series is illustrated by



Carlow.

Fig. 17.—SECTION ACROSS THE CASTLECOMER COAL-FIELD.
Castlecomer Coal-field.

G. Granite. L. Carboniferous Limestone. Sh. Shale series. Fgs. Flagstones.

* In several "Explanations" to accompany the Geological Survey Maps by the late Messrs. Jukes and Foote, and Messrs. Kinahan and O'Kelly ; with Palæontological Notes by Mr. W. H. Baily.

† Explanation of sheets 136 and 137 of the maps of the Geological Survey of Ireland.

the section (Fig. 17) of the Castlecomer Coal-field; and is more fully described in the following table of strata taken in the S.W. and S.E. of Ireland, in descending order:—

Name of Formation.	Nature of Strata.	
	Co. Kilkenny, etc.	Co. Clare, etc.
Millstone Grit	*b. Flagstone Series.* Grits and excellent flagstones with shales, about 650 feet, passing downwards into sandy shales, with annelid tracks.	*b.* Flagstones chiefly, worked at Ballynacally; annelid tracts not common.
Yoredale Beds	*a. Black Shale Series.* Sandy shales passing downwards into dark laminated shales, full of marine fossils, *Goniatites Bellerophon*, *Euomphalus*, *Aviculo-pecten*, etc.	*a. Shale Series.* Black, grey, and olive shales, sometimes arenaceous, spheroidal—with numerous fossils—*Goniatites crenistria*, *Orthoceras*, *Posidonomya vetusta*, *Aviculo-pecten papyraceus*, *Loxonema Galvani* (Baily), etc.
Carboniferous Limestone	*Upper Limestone*, forming the basis of the series.	*Upper Limestone.*

Clare, Limerick, and Cork.—This district is very extensive, stretching over a considerable tract both to the north and south of the estuary of the Shannon, but is only locally productive of coal. Mr. Weaver, who described this district many years since, truly states that the seams are few in number and importance; that they are frequently thrown

into high inclinations, and while in some places compressed to a few inches, in others they are swollen out to several feet.* The most important district is situated between the River Blackwater and Kanturk, where coal has been extensively worked.

Queen's County, Kilkenny, and Tipperary.

This coal-field is the most important, economically, in the South of Ireland, and may be designated "The Leinster Coal-field," though a considerable spur strikes southward into Tipperary. The northern portion has a generally basin-like structure, and occupies a table-land overlooking the plain of Carboniferous Limestone by which it is encircled, and upon which it rests.†

Descending Series of the Castlecomer and Killenaule Coal-fields.

(UPPER COAL-MEASURES.—Absent; probably owing to denudation.)

Fresh water or Estuarine.	MIDDLE COAL-MEASURES (Jarrow Series).—Sandstones, shales, etc., with several coal-seams from the "Jarrow Coal" upwards. FOSSILS.—*Anthracosia* (*Unio*), *Myalina*; Crustacea, Reptilia, etc.
Marine Series.	LOWER COAL-MEASURES, or "GANNISTER BEDS."—Grits, shales, and two or three thin seams of coal, with roofs containing marine shells. FOSSILS.—*Phillipsia*, *Bellinurus regina* (Baily), *Goniatites*, *Bellerophon*, *Aviculo-pecten*, and many others recently discovered. FLAGSTONE SERIES (representing Millstone Grit Series).—Beds of rippled micaceous flagstones and shales. FOSSILS.—Chiefly tracks of marine Annelids or of Molluscs.‡

* "Trans. Geol. Soc. Lond.," vol. v. See also "Explanation" to Sheet 142, by Messrs. Kinahan and Foote, "Mem. Geol. Survey."

† "Explanation" to Sheet 137, by Messrs. Jukes and Kinahan.

‡ W. H. Baily, "Explanation of Sheet 128 of the Maps of the Geological Survey, p. 15.

Marine Series.

SHALE SERIES (representing the Yoredale Beds).—Grey sandy shales, passing downwards into dark shales, with earthy limestones.

FOSSILS.—*Goniatites sphæricus*, *Bellerophon*, *Euomphalus*, *Aviculopecten papyraceus*, *Posidonomya Becheri*, *P. membranacea*, *etc.*

CARBONIFEROUS LIMESTONE.—(*a*) Upper Limestone (with beds of chert), coralline; (*b*) Middle Limestone or "Calp" beds, carbonaceous shales and earthy limestones; (*c*) Lower Limestone, compact limestone, often dolomitic.

Total thickness, 1,700 feet.

The following is the general series of coals in the Castlecomer coal-basin, by Messrs. Jukes and Kinahan, somewhat modified :—

		Ft.	In.
	Uppermost beds... ... ... about	12	0
6.	*Peacock Coal*	1	10
	Strata	45	0
5.	*Stony Coal*	3	0
	Strata	21	0
4.	*Double Seam*	5	0
	Strata and shales with *Myacites* (Anthracosia ?)	120	0
3.	*Three-Feet* or *Old Colliery Coal*	3	0
	Strata	180	0
2.	*Four-Foot Coal* ... ... 1 ft. 6 in. to	3	6
	Strata	300	0
1.	Upper and Lower *Towlerton Coals* 1 ft. 6 in. to	2	0
	Flag Series ... ... about	650	0
	Black Shale Series	500	0
	Upper Carboniferous Limestone	—	

The Upper Towlerton seam is of good quality, about 20 inches in average thickness, and known elsewhere as the *Skehana* or *Wolfhill* coal. As shown by the marine fossils which occur in the neighbourhood of the Towlerton coals, they may be regarded as the representatives of the "Gannister Coals" of England. One of them has a floor which might be mistaken for that of the Gannister Coal of

Yorkshire. The following is the remarkable series of fossils from the Gannister beds, first discovered by Mr. Aher, of Castlecomer, and afterwards collected by Mr. Hardman and Mr. Baily, who has determined their species. They are in all 16 genera and 19 species of marine forms*

Fossils from the Lower Coal-measures of Castlecomer.

CRUSTACEA ...	Phillipsia pustulata (*Schloth.*, sp.).
	Leperditia Okeni? (*Münst.*, sp.).
CEPHALOPODS	Goniatites fasciculatus (*M'Coy*).
	—— crenistria (*Phil.*).
	Nautilus (like cyclostomus, *Phil.*).
	Orthoceras Steinhaueri (*Sow.*).
GASTEROPODS	...Euomphalus (sq. inc.).
LAMELLIBRANCHS	Aviculo-pecten (Lima) alternatus (M'Coy).
	—— granosus?
	Axinus (sp. inc.).
	Edmondia (small sp.).
	Pullastra bistriata (*Portl.*).
	—— scalaris (*M'Coy*).
BRACHIOPODS	Athyris planosculata (*Phil.*).
	Orthis resupinata (*Mart.*).
	Productus semireticulatus (*Mart.*).
	Rhynchonella pleurodon (*Phil.*).
	Spirifer pinguis (*Sow.*), *or* trigonalis.
CRINOIDS ...	...Actinocrinus (joints of, abundant).

* Hull, "Quart. Journ. Geol. Soc.," November, 1877, p. 621.

CHAPTER XXIX.

NORTHERN GROUP OF IRISH COAL-FIELDS.

Leitrim Coal-fields (*Connaught*).—These coal-fields form several detached table-lands, or eminences, on both sides of Lough Allen, rising into elevations from 1,000 to 1,377 feet above the surrounding districts, formed for the most part of Carboniferous Limestone. Those to the west of the Lough are the most important, and form two small isolated basins to the north and south of the River Arigna; owing to which they are sometimes called the "Arigna Coal-fields." Of this district excellent descriptions have been drawn up by Sir R. Griffith,* Sir R. Kane,† and the late Mr. Du Noyer,‡ and more recently by Mr. Cruise of the Geological Survey of Ireland, who recently completed a detailed survey of the district, which enables us to form an accurate judgment of its structure and resources.§ The following section, reduced from one by Mr. Du Noyer, gives a good idea of the relations of these coal-tracts, and their disseverence by denudation:—

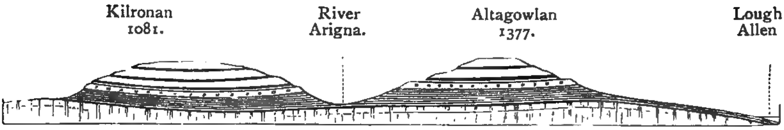
* Report on the Connaught Coal-fields (Arigna District), presented to the Royal Dublin Society, 1818.

† "Industrial Resources of Ireland," 2nd edit.

‡ "On the Bituminous Coal of the Arigna District," by G. V. Du Noyer ("Geologist Magazine," March, 1863), with map and sections.

§ Explan. Memoir to Sheets 66 and 67 (1878).

Fig. 18.—SECTION ACROSS THE LEITRIM COAL-FIELDS.



Coal-measures, Millstone Grit, and Limestone Shale, resting on a base of Carboniferous Limestone.

General Succession of the Beds.—In this district the Millstone Grit and Yoredale Beds are well developed, and interposed between the Carboniferous Limestone and coal-measures. The former rises into fine escarpments, which, at the mountain called Cuilceagh, on the borders of Fermanagh, reaches an elevation of 2,188 feet, and exhibits a fine mural cliff similar to those of the Millstone Grit of Kinder Scout, in Derbyshire.*

The coal-seams belong to the Lower Coal-measures exclusively, as shown by the marine fossils they contain (*Goniatites*, etc.); the Middle and Upper Measures having been denuded away. The Yoredale Shales, which underlie the Grit, are rich in clay-ironstones and cement stones, containing *Goniatites* and other marine shells.

Carboniferous Series at Kilronan.

			Ft.	In.
Coal-measures, 286 to 453 feet.	Sandstones and flags		110	0
	Shale, with numerous bands of clay-ironstone (fossil shells)	100 ft. to	200	9
	Coal. Third seam		0	9
	White sandstone	24 ft. to	45	0
	Grey soft clay—coal-roof ...	10 ft. to	15	0
	Coal. Second seam		2	6
	Sandstone and shale	22 ft. to	30	0
	Coal. First seam, mixed with shale ...	1 ft. to	3	0
	Sandstones and shales	17 ft. to	36	0

* This district was examined by the Author during a visit to the late Earl of Enniskillen in 1870. Here a thick series of sandstones intervenes between the limestone and overlying shales.

			Ft.	In.
Millstone Grit.	Massive coarse sandstone ...	60 ft. to	250	0
Yoredale Beds, 600 feet.	Black shales and grey flags; nodular layers of ironstone (fossiliferous) ...	600 ft. to	1,000	0
Carboniferous Limestone.	Upper, middle, and lower limestone.			

Details.—The coal of this district is bituminous. In the Aghabehy coal-basin, there is but one seam of much value, called the "top seam" (the second in the above list). It has a shale roof and sandstone floor, and averages 18 inches in thickness. The middle coal of the Altagowlan basin has a similar roof and floor, and the same thickness, and the upper seam is of equal thickness with the lower. The following analysis of the Aghabehy coal has been published by Sir R. Kane:—*

Volatile matter	23·10
Pure coke	66·15
Ashes	10·75
	100·00

Ironstones.—The clay-ironstones which occur both amongst the shales of the coal-measures, and especially amongst those of the Yoredale Beds below, are intrinsically valuable from their quantity and richness in iron. They were formerly smelted at the Arigna iron-works on the shores of Lough Allen, and it is to be hoped will again be turned to account. The following analysis by Sir R. Kane will show their average composition:—

Protoxide of iron	51·36
Lime	1·59
Magnesia	1·92
Alumina	0·98
Insoluble clay	12·82
Carbonic acid	31·33
	100·00

Proportion of metallic iron, 40 per cent.

* "Industrial Resources," 2nd edit., p. 23.

The Tyrone Coal-field (Ulster).

This coal-field is unquestionably one of great economic importance, containing as it does large quantities of bituminous coal, placed within easy reach of the manufacturing districts of the north of Ireland. It lies to the north of the town of Dungannon, and in its centre is the village of Coal Island, where the Ulster Canal places the district in connection with Lough Neagh.

In structure the Coal Island district is a basin, along the western portion of which the coal-seams crop out and have been worked, but which is overlaid and concealed beneath New Red Sandstone and Marl over probably two-thirds of its entire area to the eastward; hitherto the coals have scarcely been disturbed under this large district;* but I have come to the conclusion that it stretches to within a short distance of the shores of Lough Neagh under the newer formations.

* Except in two or three cases, coal-mining has been carried on in a very rude and unsystematic manner in this district, which ought to be the great coal-store for the north of Ireland. The Geological Surveyors have recently completed a detailed survey; and a valuable Memoir has been prepared by Mr. Hardman on the structure of this coal-field (1877).

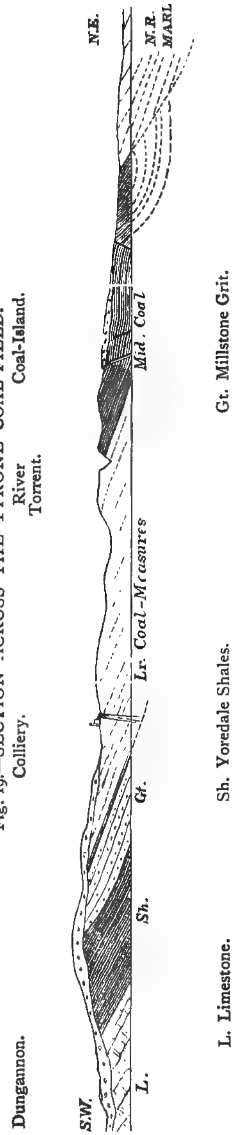


Fig. 19.—SECTION ACROSS THE TYRONE COAL-FIELD.

From the survey of Sir R. Griffith, it would appear that the Tyrone Coal-field is rich in minerals, though of limited extent. Along the banks of the river Torrent seven workable beds of coal appear, having a combined thickness of 30 feet, and included within 280 yards of strata, which are ultimately covered over by Triassic strata* (Fig. 19).

The general succession of the strata, as stated by Mr. Hardman, is as follows :†—

	Feet.
1. *Trias* or *New Red Sandstone* and *Marl*, which rests unconformably on the coal-measures at Coal Island	—
2. *Middle Coal-measures.*—Soft sandstones, shales, and fire-clays, with ironstones and coal-seams	930
3. *Lower Coal-measures* (*Gannister Beds*).—Hard sandstones and grits, slaty shales with a few coal-seams and ironstones, thickness about	1,000
4. *Millstone Grit.*—Coarse grits and sandstones, probably ...	200
5. *Yoredale Beds.*—Black shales, sometimes calcareous—sandstones and ironstones	600
6. Carboniferous limestone...	2,000
Total	4,730

The Annahone District is much smaller. It is 1 mile long, and ½ mile broad. It may, therefore, contain 320 acres. Sir R. Griffith states, however, that it is probable the district may extend a considerable distance farther to the south and east, and that coal may be wrought from beneath the New Red Sandstone. The coal-field is, moreover, covered to a considerable depth with drift deposits, which render the strata difficult of access.

* "Geological and Mining Surveys of Tyrone and Antrim." Dublin, 1829.

† "Explan. Mem.," Sheet 35, p. 10. The fossils are enumerated and described by Mr. Baily. *Ibid.*, p. 14.

The following is some account of the coal-seams at Coal Island in descending order :*—

	Yds.	Ft.	In.
Upper Coal (impure)	0	2	2
Strata	12	1	0
Annagher Coal (soft quality)	0	9	0
Strata	18	1	0
Bone Coal	0	3	0
Strata	13	0	0
Shining Seam	0	2	10
Strata	26	0	0
Brackaveel Coal (good quality)	0	5	0
Strata	28	0	0
Gortnaskea Coal {cannel, 2 feet; coal, 4 ,,}	0	6	0
Strata	25	0	0
Baltiboy Coal (sulphureous)	0	3	0
Strata ... ...(about)	65	0	0
Derry Coal (good quality)	0	4	6
Strata with two thin seams	50	0	0
Yard Coal (good quality)	1	0	0
Strata with two thin seams, and of uncertain thickness	(unknown)		
Creenagh Coal (with 14-inch cannel)	1	1	6
Strata, only partly proved and of uncertain thickness	(unknown)		
Drumglass Main Coal (variable)	[illegible]	1	10
Strata (variable)	10	0	0
Lower Coal ... ... 1 ft. to	0	2	0

Present State of Coal-Mining in Tyrone.—On the occasion of a recent visit to this district for his Report on the present state of coal-mining, the author was much disappointed to find that the industry had practically ceased, and that the pits of Drumglass, and Coal Island were

* For analyses of coals and ironstones by Mr. Hardman, see "Proc. Roy. Irish Acad.," 2 sec., vol. ii.

closed. The only works in progress were close to the latter village, where excellent fire-clay—with a little coal for the furnaces—was being extracted for making pottery and tiles. Perhaps the day may come when the great manufacturing province of Ulster may awake to the discovery that while it is dependent on England and Scotland for its coal supply, there is a large undeveloped quantity of mineral fuel at its own door. It will be seen, on reference to table (page 261) that the output of coal from the whole of Ireland only amounted to 102,812 tons in 1903.

Antrim Coal-field.

The Antrim Coal-field, in point of geological interest, is unsurpassed by any other district in Ireland. It extends along the coast of Ballycastle Bay on the north, and Murlogh Bay on the south, separated from each other by the magnificent mural cliffs of Benmore or Fair Head, formed of columnar dolerite, which rise boldly from the sea to a height of 636 feet. The length of the coal-field is 4 miles, and the average breadth $1\frac{1}{2}$ miles; coal has been wrought here from an ancient period.

The geological structure of this district has been investigated by several observers, including Dr. Berger,* Dr. Bryce,† and Sir R. Griffith, who, in 1829, drew up an able Report, illustrated by drawings, for the Royal Dublin Society.‡ The most recent treatise is one by myself, in

* "On the Geological Features of the Northern Counties of Ireland," "Trans. Geol. Soc. Lond.," 1st Series, vol. iii.

† "On the Geological Structure of the N.E. part of the County Antrim," *ibid.*, 2nd Series, vol. v.

‡ "Geol. and Mining Survey of the Coal-districts of Tyrone and Antrim." Dublin, 1829.

which the question of the geological age of the coal-bearing rocks is discussed;* a question to which I shall presently return.

Ballycastle Carboniferous series.—This series may be arranged in the following divisions:—

(3) *Upper Beds.* About 240 feet in thickness.	Reddish and grey sandstones, sometimes coarse-grained and conglomeratic; shales with seams of coal, clay-band and black-band ironstone. Fossils: *Lingula squamiformis; Sagenaria* (*Knorria*) *imbricata, Sigillaria Lepidodendron, Stigmaria*, etc.
(2) *Middle Beds.* 55 feet.	Two beds of compact argillaceous limestone, 9 feet in thickness, fossiliferous, and embedded in calcareous shales with numerous fossils. Fish: *Orthoceras Steinhaueri, Bellerophon Urii, Murchisonia angulata, Leda attenuata, Axinus deltoides, Rhynchonella pleurodon, Productus giganteus, Fenestella antiqua, Archæocidaris, Urii*, etc.
(1) *Lower Beds.* Thickness considerable but unknown.	Red and yellow sandstones, sometimes coarse, with beds of shale, and a seam of black-band ironstone; the base ot the series being the conglomerate of Murlogh Bay.

The entire thickness of the series is unknown, but probably exceeds 1,200 feet. The base is a quartzose conglomerate resting upon contorted mica-schist, with veins of quartz, as seen at the south end of Murlogh Bay.

Coal-series.—The coal-series of Ballycastle Bay, as ascertained at the mines at work in 1874, is as follows:—†

* "On the Geological Age of the Ballycastle Coal-field," etc., with Palæontological Notes by Mr. W. H. Baily, F.G.S., "Journ. Geol. Soc. of Ireland," vol. ii, Part III, New Series, 1871.

† Furnished to the Author by Mr. Gray, the mine manager, Ballycastle Bay.

	Ft.	In.
Top, or *First Coal* (splint seam)	3	0
Sandstones and shales	30	0
Second Coal (Hawksnest seam)	3	0
Strata, with black-band ironstone	240	0
Third Coal (main seam)	4	0
Strata, with black-band ironstone below the main coal, in some places	60	0
Limestone (same as that in section above)... ...	8	0
Strata (shales and sandstones)	240	0
Lower Black-Band Ironstone (by boring)	1	0
Total	589	0

In Murlogh Bay the section is different, but the beds of coal are considered to represent those in Ballycastle Bay. Here they are capped by columnar basalt, and a dyke of this rock intrudes itself amongst the strata, changing some of the coals into anthracite. Other basalt or dolerite dykes occur, traversing the strata in Colliery and Ballycastle Bays; and an enormous mass of this rock forms the limit in a northerly direction of mining operations. The strata are also traversed by several faults which displace the beds of coal.

The following is the section visible on the northern side of Murlogh Bay from the top of the cliff downwards, as given by Sir R. Griffith :—

Section in Murlogh Bay.

	Ft.	In.
Columnar Greenstone ... ... about	100	0
Brownish-Red Sandstone	20	0
Bituminous Coal	1	0
Red Sandstone	80	0
Black Shale	6	0
White Mine Coal (highly bituminous)	2	6
Brownish-Red Sandstone	40	0

	Ft.	In.
Bituminous Coal	0	6
Red Sandstone	20	0
Black Shale	10	0
Bituminous Coal (Goodman's vein)	2	6
Black Shale	60	0
Uninflammable Carbonaceous Coal...	2	6
Black Shale passing into flinty shale	2	0
Second Columnar Greenstone (basalt)	70	0
Black Shale	2	0
Non-Flaming Coal, with thin beds of Black Shale	8	6
Black Slate (base not visible)	10	0
Total	437	6

Geological Age of the Antrim Coal-series.—In comparing the succession of strata at Ballycastle with those of the Ayrshire and Lanarkshire coal-fields, we cannot fail to be struck by the several points of analogy they present. Amongst these are (1), the thick beds of red sandstones and conglomerates, which form the lower part of the series; (2), the occurrence of beds of black-band ironstone; (3), also of earthy limestone with Carboniferous Limestone fossils, and of a marine bivalve (*Lingula squamiformis*) over one of the coal-seams of the upper division. These, and other considerations, have led me to the conclusion, that the Antrim coal-series belongs to the same geological horizon as that of the Lower Coal and Ironstone Series of Scotland, which, as I have already shown, occupies the position of the "Yoredale Series" of the north of England. The base of this series is the Carboniferous Limestone, represented in the Ballycastle Coal-field by the thin band of limestone, 8 feet thick, described above, while the underlying reddish sandstones, shales, etc., are referable to the "Calciferous Sandstone series" of the centre of Scotland. It will thus be evident that the Carboniferous Lime-

stone has undergone a remarkable amount of deterioration as a limestone formation in its northerly extension in Ireland as well as in Scotland.*

Black-band ironstone has been largely mined, and calcined on the spot, from whence it can be exported to the furnaces on the opposite coast of Ayrshire.

RESOURCES OF THE IRISH COAL-FIELDS.

The estimates of the resources of the Irish Coal-fields in 1870 were entrusted to the Author, upon the decease of Professor Jukes, one of the Royal Commissioners; and the following are the results of the available quantities of coal, as published in the Report, and in arriving at which I had the assistance of my colleagues of the Geological Survey, Messrs. G. H. Kinahan and J. O'Kelly; they amounted to 182,280,000 tons; the amount for 1904 may be put at 174,458,000 tons, being so much less by the quantity worked out in 30 years.

The quantity of coal raised in Ireland is comparatively small, and much below what it ought to be, if all the coal-fields were properly developed. It will be seen from the above estimates that the northern district of Tyrone has considerable resources in mineral fuel, which are at the present time made use of to a very limited extent. I cannot, however, but look forward to an improvement in this respect, when the facts of the case become more generally known, through the publications of the Government Geological Survey and the reports of the Commissions of 1871 and 1904.

In 1903, the quantity of coal returned as raised in

* "Trans. Roy. Geol. Soc. Ireland," vol. ii, p. 260 (1871).

Ireland was 102,812 tons, a considerable decrease from former years.*

Output of Coal in the United Kingdom for the Year 1903.

(According to Districts under the Inspectors of Mines.)†

—	Tons.	Counties Included.
East Scotland	16,398,441	The Lothians, Fife, and Perth.
West Scotland	18,593,799	Stirling, Lanark, and Ayr.
Newcastle	25,902,627	Northumberland and Cumberland.
Durham...	24,203,110	Durham and North Riding.
York and Lincoln	28,527,958	West Riding, etc.
North and East Lancashire ...	11,354,756	North and East Lancashire.
West Lancashire and North Wales	16,782,934	West Lancashire, Flint, and Denbigh.
Midland Coal-fields	29,372,921	Derby, Notts, Leicester.
Staffordshire Coal-fields ...	14,562,062	Stafford, Salop, Worcester, and Warwick.
Cardiff, South Wales	21,980,282	Brecon and Glamorgan (in part).
Swansea, South Wales ...	9,502,477	Pembroke, Carmarthen, and Glamorgan (in part).
Southern Coal-fields	13,040,116	Monmouth, Somerset, Gloucester.
Ireland	102,812	
Total	**230,324,295**	

	Tons.
Preceding year	227,084,871
Increase	3,239,424

There were 3,449 mines in operation, employing 842,066 persons during the year 1903, being an increase of 17,275 on the previous year.

General Result.—The quantity of coal extracted from

* "Statistical Returns," Home Office, 1903.

† From the "Statistical Returns" presented to Parliament by the Home Office for 1903.

the British area between 1870 and 1903, inclusive, was 5,694,928,508 tons, giving an average increase of 3,633,432 tons per annum, or a percentage 2·34 for the period. This may be a guide for a certain period in the future; but it would be impossible to deduce from the tables for each year any general rule of progression, the variations being so irregular from year to year, and ranging from 14·27 in 1894 to ·03 in 1898.

CHAPTER XXX.

ON THE QUANTITY OF COAL IN THE CONCEALED COAL-FIELDS OF CENTRAL ENGLAND.

Coal-resources of the British Isles.

BESIDES the coal stored in the known or visible coal-fields, it is unquestionable that very large quantities lie concealed beneath Permian, Triassic, and even Liassic strata beyond the margins of these coal-fields themselves. The extent and subterranean limits of these concealed reservoirs have been the subjects of investigation on the part of physical geologists for some years past; but it is only very recently that our knowledge of the geological structure of the British Isles has been sufficiently advanced to enable us to arrive at anything like definite results on this question.

The solution of this interesting problem depends on the proper determination of three distinct branches of investigation. The first of these is the restoration of the original limits, or margins, of the Carboniferous rocks; secondly, the extent and direction of the areas of upheaval and depression over which the subsequent terrestrial movements have taken place; and thirdly, the amount of denudation which has accompanied or followed these terrestrial movements.

As the determination with any degree of precision of these severally simple problems, merging into the complex

one, depended on a multitude of minute observations made over the whole area, and properly laid down on maps, the question itself was not ripe for solution until the country had been geologically mapped by the Government Surveyors; so that, had the attempt at solution been made at an earlier period than the present, it must have failed, simply from the want of the necessary details. It was, therefore, fortunate that the appointment of a Royal Commission (part of whose duty was to report upon this question) was reserved for the present time, when the Government Surveyors had extended their investigations over nearly the whole of the districts of England occupied both by the coal-fields and the more recent formations, and were in a position to supply all the necessary details for the proper consideration of this complex problem, in addition to the voluntary assistance readily tendered by many private observers.

One of the earliest attempts to define the limits of the concealed coal-fields was that made by the late distinguished Director-General of the Geological Surveys, Sir Roderick Murchison, who, upon the occasion of the meeting of the British Association at Nottingham, in 1866, read an essay on the subject before the Geological Section.* In this paper the writer combats the view of the existence of workable coal, either under the Cretaceous rocks of the south of England, or of the Triassic rocks east of the Malvern Hills; while he points out that these hills themselves on the west, and the Cambrian Rocks of Charnwood Forest on the north-east, then full in view from Nottingham Castle, formed the "salient promontories" of

* "On the Parts of England and Wales in which Coal may or may not be looked for."—"Trans. Brit. Assoc.," 1866.

the southern coast line, or margin, of the original coal-fields.

Having for several years, while engaged on the survey of the midland and western counties of England, kept the question steadily in view, as one of the very highest economic importance, I had the gratification of laying my views before the Royal Coal-Commission of 1871, in which I entered into the whole quesion, as far as it related to the midland and northern counties; and at the request of the Committee, to which this branch of inquiry was delegated, I prepared a small map, showing what appeared to be the probable subterranean limits of the coal-formation.* These views were shortly afterwards repeated, or expanded, in a memoir, which I drew up for the Geological Survey, "On the Triassic and Permian Rocks of the Central counties of England" in 1869.†

In his memoir on the "Geology of the South Staffordshire Coal-field," the late Prof. Jukes had thrown considerable light on the question of the limits of the coal-measures of the central counties towards the south, and had also recognised in the rocks of Charnwood Forest the original margin of the old Carboniferous area—a question on the determination of which the whole internal structure of the central counties hinges.‡

* The evidence and map are published with the Report of the Commission (1871), vol. ii.

† "Distribution of the Coal-measures beneath the Triassic and Permian Rocks," chap. xi, p. 109.

‡ "Geol. South Staffordshire Coal-fields." Preface to 2nd edit., 1859.

CHAPTER XXXI.

VISIBLE COAL-FIELDS.

HAVING discussed the question of the extension of the coal-measures under the newer formations in districts where this is purely inferential, I proceed to offer statistical estimates of the quantity of coal still remaining both in the visible and known concealed coal-fields. I will first take the estimate of the Commissioners in 1870, and, in a separate column, these estimates corrected down to the year 1903.*

On glancing at the results (see p. 267) for the resources of 1903 as compared with those of 1870, the most striking discordance observable is that between the returns for the "Midland" coal-fields, including those of Yorkshire, Derbyshire and Nottinghamshire. But this disagreement is more apparent than real; and is due to the fact that the late Mr. J. T. Woodhouse, the Commissioner for 1870, limited his estimates very nearly to the area extending westward from the margin of the Magnesian Limestone, only taking a marginal strip under this formation where he considered the coal had been "proved" by actual experiment. Mr. A. C. Briggs, on the other hand, has included in his estimates a much larger area under the newer formations, bounded by a line drawn from Peckfield Colliery, near Leeds, to Haxey borehole and thence by Gedling,

* The total quantity of available coal in the United Kingdom estimated under the above divisions amounts, therefore, to 100,867,660,096 tons down to the year 1904.

Returns of Estimates of Coal-reserves by the Commissioners of 1870 and 1904.

I. Visible Coal-fields to 4,000 Feet in Depth.

Commissioner.	No.*	Name of Coal-field.	Estimated Available Quantity Remaining for use in 1903.	Estimated Available Quantity Remaining in 1870.	Commissioners of 1871.
			Tons.	Tons.	
Sir W. Thomas Lewis ...	1	South Wales and Monmouth	26,470,996,579	19,278,272,240	Messrs. Vivian and Clark.
Do. ...	2	Forest of Dean ...	258,533,447	265,000,000	Mr. Dickinson.
Do. ...	3	Bristol and Somerset ...	4,151,293,028	4,218,970,762	Sir J. Prestwich.
Messrs. Lapworth and Sopwith	4	Warwickshire	846,572,518	458,652,714	Mr. Woodhouse.
Do. ...	5	South Staffordshire ...	1,415,448,072	1,906,119,768 (5 and 6)	Mr. Hartley.
Do. ...	6	Shropshire, Forest of Wyre, etc.	320,993,699		
Do. ...	7	Leicestershire	1,825,458,551	836,799,734	Mr. Woodhouse.
Do. ...	8	North Staffordshire ...	4,368,050,347	3,825,488,105	Mr. Elliot.
Mr. A. Strahan... ...	9	Flintshire	771,368,012	2,005,000,000 (9 and 10)	Mr. J. Dickinson.
Do. ...	10	Denbighshire	965,099,817		
Prof. E. Hull, Mr. Strahan, and Sir G. Armytage	11	Lancashire	4,238,507,727	5,345,620,000	Do.
Do. ...	12	Cheshire	291,832,271	200,000,000	Do.
Mr. A. C. Briggs ...	13	Yorkshire, Derbyshire, and Nottinghamshire	25,173,794,921	12,220,000,000	Mr. J. T. Woodhouse.
Sir Lindsay Wood ...	14	Northumberland ...	5,509,625,641	3,813,276,846	Sir G. Elliott and Mr. Forster.
	14	Durham	5,271,116,346	4,473,250,000	
Do. ...	15	Cumberland	1,527,708,805	405,203,792	Do.
Mr. J. S. Dixon ...	16	Scotland	15,681,450,000	9,843,465,000	Mr. Geddes.
Prof. E. Hull	17	Ireland...	174,458,000	155,680,000	Prof. E. Hull.

* For details regarding quantities in each county, see back, p. 268.

Edwalton, and Ruddington boreholes to Nottingham. This is a purely artificial limit. Messrs. J. E. Mammatt and John Longbotham have returned 483,844,875 tons for seams lying below 4,000 feet.

2. Concealed Coal-fields.

Summary of probable Amount of Coal under Permian and other overlying Formations at Depths of less than 4,000 feet, allowing for loss and other contingencies, and ignoring inferior and thin seams.

Districts.	Under.	Square Miles.	Tons.
Warwickshire	Permian	73	
Warwickshire, south of Kingsbury ...	New Red	5	
Leicestershire, Moira district... ...	Permian	15	
Leicestershire, Coleorton district ...	New Red	25 to 28	
District between the Warwickshire and South Staffordshire Coal-fields	Permian and New Red	116	
District between South Staffordshire and Shropshire Coal-fields	Do.	195	12,647,344,000
Between the South Staffordshire and Coalbrook Dale Coal-fields to the Cheadle and North Staffordshire Coal-fields	Do.	200	
East of the Denbighshire Coal-field...	Do.	50	
West and S.W. border of the North Staffordshire Coal-field	Do.	50	
Cheshire, west of the Kerridge ...	Do.	9	
Cheshire, between Woodford Fault and Denton	Do.	36	
Lancashire, east and west of Manchester	Do.	30	2,986,500,000
Lancashire, west of Eccles and Stretford to Prescott, Runcorn, and Hale-on-the-Mersey	Do.	130	
The Wirrell, the Mersey, and country to the north	New Red	200	
Yorkshire, Derbyshire, and Nottinghamshire	Permian and New Red	2,550	23,000,000,000
Vale of Eden	Permian	40	800,000,000
Ingleton and Burton	Do.	3	
Severn Valley	New Red Marl	45	
Ireland, Tyrone (Prof. Hull)... ...	New Red Marl and Sandstone	2,400 acres	27,000,000

Kent.—The Commissioners report that, in view of the fact that the limits of the coal-measures in Kent cannot be determined, and that our knowledge of the coals is founded on two borings only, they find it impossible to make any estimate of the amount of coal likely to exist under the county of Kent.

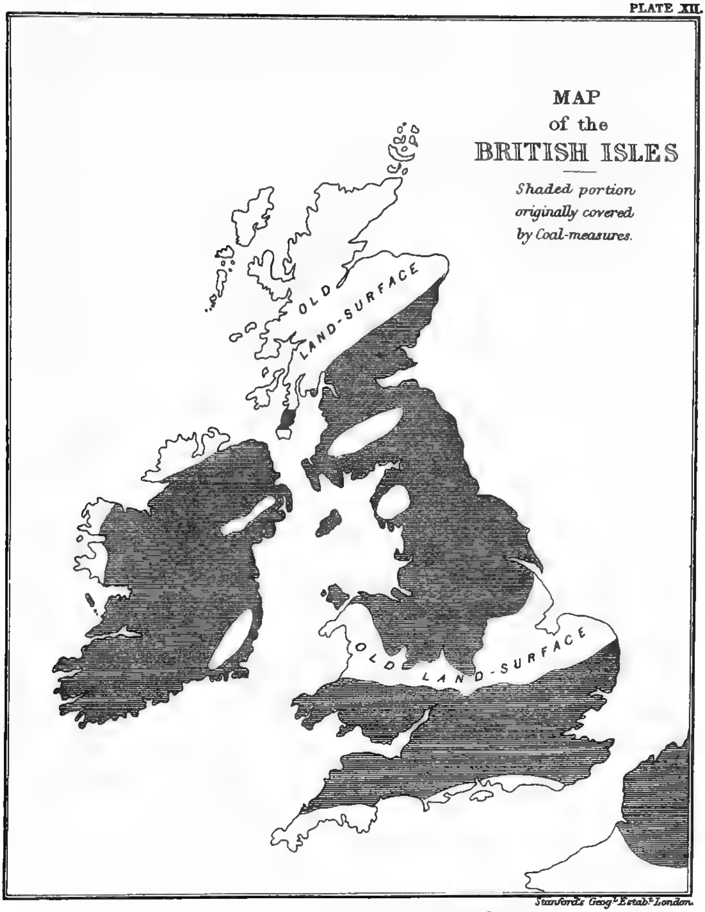
But, while these pages are passing through the press, coal has actually been brought to the surface through one of the shafts of the colliery at Shakespeare's Cliff, from the first workable seam, 2 feet in thickness; as I have had an opportunity of visiting the works, I can state that the coal is of good quality, bright and clean; and I consider the future of this colliery as highly encouraging.

CHAPTER XXXII.

THE EASTERN LIMITS OF THE MIDLAND COAL-FIELDS UNDER THE NEWER FORMATIONS. (With Map.)

WHEN we look at a geological map of the Midland district of England, we observe several large dark patches surrounded by still larger tracts of red colour of various shades. The dark areas are the coal-fields rising from below the red formations known as Permian and Trias, which may have originally overlain them, but have been denuded away, so as to reveal the Carboniferous strata which once lay below. These coal-fields, four in number, are those of North and South Stafford, Leicestershire, and Warwickshire; and at first sight it might be supposed that they were not only connected with each other physically beneath the newer formations which now appear to separate them, but that they stretched away indefinitely to the south and east under Northamptonshire and East Anglia, being overlain by the Triassic, Liassic, and still newer formations of these counties.

Such, indeed, was once a favourite theory, until rudely dispelled by recent investigations, which go to show that the Coal-fields of the Midland Counties have a very restricted extension under the Mesozoic formations surrounding them; for the numerous borings that have been put down at various points under the wide area ranging from the Trent above Nottingham to the Thames all tend



London. Hugh Rees, Ltd.

to show that the view of Sir R. I. Murchison expressed in 1866 was indeed a remarkable case of intuitive reasoning when he stated his conviction that coal did not exist under the Eastern Counties.*

Historical.—A few years previously, however, the late Prof. J. B. Jukes, in the preface to the second edition of his "Memoir on the South Staffordshire Coal-field,"† had pointed to the evidence afforded by the position of the formations at the southern end of that coal district in the neighbourhood of Hales Owen—that a land surface, or chain of islands, composed of Silurian (or Cambrian rocks), occupied the region of the coal-field during the Lower Carboniferous period, rising unsubmerged, while the beds of Mountain Limestone and Millstone grit were being deposited in the area to the north; the effect being that these beds were absent in the southern part of the country from below the coal-measures, although developed in great masses in the northern portion adjoining Derbyshire and Yorkshire; and he adds: "This land must have been depressed wholly or in part, while the coal-measures were being deposited, and as it slowly sank beneath the waters, sheet after sheet of coal-bearing strata extended over it, till, perhaps, the whole was finally buried under one wide-spread sub-aqueous coal-measure plain."‡ There was a limit however, towards the south; for it is quite certain that the coal-measures terminate along a shelving ridge of Silurian beds in the neighbourhood of the Bromsgrove, Lickey and Clent Hills, in consequence of which the coal seams become unworkable, and ultimately die out.

* "Report of the British Association," vol. xxxvi, pp. 57–63.

† "Mem. Geol. Survey," 1859.

‡ *Ibid.*, Preface, p. 13.

As time went on, however, and fresh light was thrown on this important physical problem, I ventured, in 1869, to state my view that this supposed chain of islands was in reality the margin of a ridge of ancient Palæozoic land which separated the coal formation of the Midlands and North of England from that of the South of England and South Wales, and in harmony with the views of Sir R. Murchison that "the barrier" of ancient rocks extended into the region of East Anglia.* If the reader will refer to the little map (p. 272) in which I have endeavoured to represent the areas of the British Isles which were originally covered by the coal formation (shown by shading), and those which remained uncovered, because unsubmerged, the views I am here putting before him will be rendered more plain; and I have seen no reason since that map was published, in 1881, to modify the views there expressed.

These views, as will be shown presently, are supported by the evidence derived from borings. But, in adition, we have indications afforded by the presence of pre-Carboniferous rocks in parts of the Counties of Leicester and Warwick, where they thrust themselves through the nearly horizontal strata of the Triassic period in isolated masses, and are probably the more prominent parts of the old ridge above referred to, uncovered by denudation.

These pre-Carboniferous rocks may be recognised in the remarkable isolated mass of slates, grit, and igneous rocks of Charnwood Forest, whose sharp ridges and bold cliffs suggest (in conjunction with the characters of the rocks themselves) a diminutive model of North Wales in the heart of England. They are also to be recognised in the bosses

* "On the Triassic and Permian Rocks of the Midland Counties of England," "Mem. Geol. Survey," 1869.

of syenite and other igneous rocks of Mount Sorrel, Barrow Hill, and Stoney Stanton—all emerging from the plain of Triassic Marl, and indicating the presence of rocks older than the Carboniferous under the centre and eastern side of Leicestershire, and presumably the adjoining district to the south and west. Proceeding in our survey southwards we find the quartzites and slates of Atherstone, determined by Prof. Lapworth to be of Upper Cambrian age, forming the eastern margin of the Warwickshire Coal-field, while borings undertaken some years since by the Netherseal Colliery Company on the western margin of the Leicestershire Coal-field indicate similar conditions; in fact, Cambrian quartzites and schists were passed through, the whole of the Lower Carboniferous rocks with the part of the coal-measures being found to be absent.*

Further Boring Experiments in the Midland and Eastern Counties.—In *Northamptonshire*, the borings have generally been put down in search of water, but they have been useful in revealing the nature of the strata. In at least two of these lower Palæozoic rocks have been proved below those of Triassic age—

(1) At Orton, a village 10 miles north of Northampton, hard grits and slates, probably of Cambro-Silurian age, were reached below the New Red Marl.†

(2) Near the town of Northampton, which is built on

* At Sapcote, east of Hinkley, a boring was put down which reached shales or slates 830 feet thick below 492 feet of newer strata. It was supposed that these were coal-measures, but, as no beds of coal were passed through in so thick a section of shale, they are more probably of Silurian or Cambrian age. This boring is mentioned by Sir A. C. Ramsay ("Rep. Coal Commission," 1871, vol. i, p. 134).

† I use the term "Cambro-Silurian" to designate old Palæozoic rocks destitute of fossils, and therefore of uncertain age.

the Lias, several borings have been put down in which pre-Carboniferous rocks have been proved. The Triassic Marl is thin and in one place absent; but it is very remarkable that Carboniferous Limestone, capable of identification by the fossils, has been proved at a depth of 890 feet.* The existence of this formation may be considered to show that coal-measures were originally present, but if so, they have been denuded away before the Triassic period.

(3) In Buckinghamshire and Herts, borings have been made at Ware, Cheshunt, and Culford, by which the existence of Silurian beds have been proved below the Cretaceous.†

(4) In Suffolk the most important boring was that put down in the valley below Crepping Hall, near Stutton, on the north bank of the River Stour. As this gives a clear indication of the nature of the strata underlying the Cretaceous beds in East Anglia, I here give an abbreviated list of the strata passed through :—

	Feet.
1. Gravel, etc.	16
2. Tertiary Strata	54
3. Upper, Middle, and Lower Chalk ...	874
4. Gault Clay	50
5. Cambro-Silurian (?) Grits and Slates ...	534
Total	1,528

The beds (No. 5) consist of grey slates, resting on purple and dark grey grits and and slates, much fissured,

* Determined by the late Mr. Etheridge.

† At Culford dark slates with limestone nodules and dipping at 40 degrees were pierced through to a depth of 20 feet, and are probably of Lower Silurian age.

destitute of fossils, and with a high dip towards the south. It is possible they may be of Lower Devonian, though more probably of a much older, age.

The boring made at Harwich in 1854–57, in which "black slaty rock," 44 feet in thickness, and with a slaty fracture, was found. It was formerly supposed to be of Lower Carboniferous age, on account of an impression resembling that of a *Posidonia*, which, however, was considered by the late Mr. Etheridge to be a deception.* The slate rock was entered at a depth of 1,025 feet below the Gault clay, and as the boring is only a short distance from that at Stutton, it is most probable that the rock belongs to the same series of pre-Carboniferous beds.

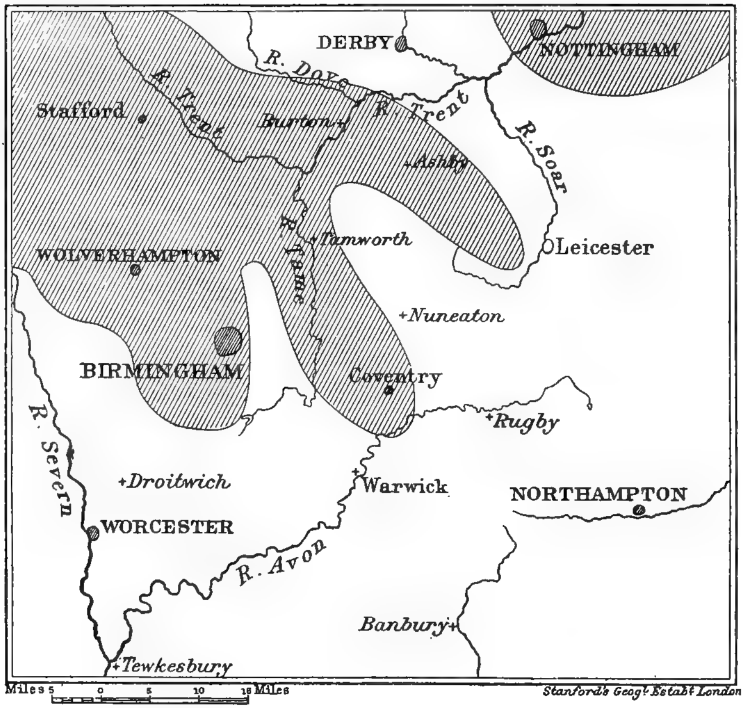
In proximity to the last, but further south, is the boring at Weeley, in Essex, in which bluish clay slate, with a high southerly dip, was reached at a depth of 1,094 feet below the Gault; this rock evidently belongs to the same series as that of Stutton and Harwich, and is therefore probably of Cambro-Silurian Age.

Hertfordshire has yielded one of the most interesting results to boring operations north of the Thames Valley, owing to the fact that at the town of Ware, below Cretaceous strata, and at a depth of 800 feet, shales with characteristic Wenlock fossils were penetrated. The specimens were examined by the very best authority on such a matter, the late Mr. Etheridge,† and determined by him to be of "Wenlock" age. From all this, we conclude that

* Mr. W. Whitaker concurs in the view that it is not a fossil shell. 'Minutes of Evidence," Coal Commission, November 24, 1903.

† Etheridge, "Presidential Address, Section C." "Journ. Geol. Soc.," vol. xxxvii, p. 231. The Wenlock Beds belong to the Lower Division of the Upper Silurian Formation.

the coal formation is limited in its extension from the Midland Counties, and terminates in the form of a succession of bays and headlands (so to speak), as represented in the little map below, where the dark shading indicates



Sketch Map of the Midland District to show approximate limit of the coal-formation. Shaded portion, area of coal-measures.

the concealed coal-bearing area under the more recent secondary formations.

Conclusion.—From the above series of borings, carried out

at intervals over a wide area of East Anglia and adjoining Central Counties of Leicester and Northampton, it will be seen that there is no evidence whatever of the existence of coal-measures under the Mesozoic formations so far as the evidence has gone; and this conclusion is abundantly amplified by the result of experiments on both sides of the Valley of the Thames, which we now proceed to consider. As a general result we find as we proceed from North to South a succession of strata, commencing with the Cambrian in Leicester and Warwick, then followed probably by Lower Silurian, then by Upper Silurian, and finally by Devonian, as will now be shown, under the Thames Valley. This succession is illustrated by the generalised section, p. 276, drawn in a direction from North to South.

Borings under London.—The borings for water under London are so numerous, and in several cases so conclusive as regards the formations underlying the Tertiary and Cretaceous strata of the London Basin, that we are absolutely certain that the bed-rock of all the formations bordering the Thames consists of Devonian. The earliest and, therefore, the most interesting experiment, determined by fossil evidence, was that carried out at Messrs. Meux's brewery, in Tottenham Court Road, in the year 1877, at a level of 85 feet above Ordnance datum, of which the following is a concise account:—*

* The fossils were identified by Etheridge.

Boring at Meux's Brewery.

	Feet.
1. London Clay, etc. (old well)...	156
2. Chalk	652
3. Upper Greensand	28
4. Gault Clay	160
5. Phosphatic nodules and sandy limestone with casts of fossils —Lower Greensand?	68
6. Upper Devonian Beds, red and purple shales and sandstones; with fossils—*Spirifer disjuncta*, *Rhynchonella cuboides*, *Edmondia*, *Orthis*, *etc.*	80
Total depth	1,144

The Devonian beds had a dip of 35 degrees, but the direction was not ascertained. The section is given in more detail by Prestwich.*

1. At Kentish Town, a boring was put down in or about 1856 when, under the Gault, and at a depth of 1,113 feet, red and grey sandstones were passed through for a thickness of 188 feet. The cores were examined by Prof. Prestwich,† and from their resemblance to the upper Devonian beds of the Mendips were determined to be of Devonian age.

2. At Crossness, at a depth of 1,000 feet from the surface, red sandstones and shales, also presumably of Devonian age, were passed through to a thickness of 52 feet.

3. At Richmond, in a boring for water, at 17 feet above Ordnance datum, similar purple shales and sandstones, presumably of Devonian age, were passed through for a thickness of 207 feet; the total depth of this boring was 1,445 feet.

4. At Streatham, a boring for water was commenced some

* "Quart. Journ. Geol. Soc.," vol. xxxiv, p. 902, 1878.

† "Rep. Coal Commission, 1870–1," vol. i, p. 149.

years since by the Vauxhall Company, with the following results :—

	Feet.
Tertiary—Alluvium and Tertiary Strata	241
Cretaceous—Chalk, 652 feet ; Gault, 188 feet	840
Jurassic—Oolitic limestone (beds horizontal)	38
*Devonian** or *Carboniferous*—Grey and purple grits, with marls and small pebbles; at 1,258 feet small fish teeth and carbonaceous matter were found	139
Total	1,258

The above nearly completes the series of borings made along the Thames Valley which have penetrated into the Palæozoic rocks. Their geological age might have remained in some uncertainty had it not been for the identification of the beds under Tottenham Court Road by means of the fossils; but even had these failed, it might have been well inferred from their characters and position that they were necessarily of Devonian age. The only other alternative formation to which they might have been referred would have been the Trias; but we have no evidence of the presence of Triassic strata in the corresponding sections on the Continental side of the English Channel, where we find the key to the structure of the English area along the line of the great east and west folds which dominate the Palæozoic formations.

There is one important boring which remains to be described before we leave this subject, namely, that at Burford in Oxfordshire. I have left it till the end of the series because it is isolated and somewhat exceptional.

Burford, Oxfordshire.—The discovery of coal at Burford,

* The dip of these beds was at an angle of 35 to 40 degrees, and it is quite possible that they may belong to the passage beds from the Devonian to the Carboniferous.

near Oxford, at a depth of 1,184 feet below Triassic strata,* is a circumstance of much interest, as it indicates the existence of a coal basin (or trough) at a considerable distance from all other beds of the same geological age. On looking at the map of the British coal-fields accompanying this volume it will be seen that the Burford Coal-measures are in a direct line with those of South Wales and the Forest of Dean, west of the Severn; but that they are disconnected with the latter is unquestionable, as the Forest of Dean Coal-field is a true basin, bounded on all sides by Millstone Grit and Carboniferous Limestone. On the other hand, we find the Upper Silurian beds beneath the Gault clay at Ware, in Hertfordshire, just in the line of the same strike as that of South Wales and the Forest of Dean. We may, therefore, infer that the coal-measures under Burford form an isolated trough or basin, probably of no great area, under the Jurassic strata of Oxfordshire, but certainly at a depth at which they may be easily worked for the benefit of the surrounding district, should it be ultimately proved that the seams of coal are of sufficient value for working.

The details of the boring as given by Prof. Boyd Dawkins are as follows:—†

	Feet.
Blue Clay	30
Lower Oolite Limestone	120
Liassic Series	600
Rhœtic	20
Triassic Marl	280
,, Sandstones	130
Coal-measures	220
Total	1,400

* The boring was carried out by Mr. Fox in 1877.

† "Trans. Geol. Soc.," Manchester, vol. xiv.

CHAPTER XXXIII.

GENERAL SUMMARY OF COAL RESERVES.

(*As determined by the Royal Commission of* 1904.)

THE following is (in round numbers) the presumable quantity of coal in reserve in the year 1903, at depths not exceeding 4,000 feet, and in the cases of Northumberland, Durham, and Cumberland extending about 3½ miles out to sea.

	Tons.
Quantity of available coal in visible coal-fields	100,867,660,000
In concealed coal-measures	39,483,844,000
Total	140,351,504,000

It therefore appears that there exists within the limit of depth above stated, and after making due allowance for the loss and waste inseparable from mining, a supply of coal of over ONE HUNDRED AND FORTY THOUSAND millions of tons,—a supply which, if drawn upon at the rate of 230 millions of tons, the quantity for 1903, would be sufficient to last for OVER 610 YEARS. But it is impossible to regard the subject from this point of view; first, because the produce of the coal-fields is a variable and increasing quantity; and secondly, because the coal can never be exhausted otherwise than by a gradual and slow process.

To this question we shall return: meanwhile, the result of the calculations of the Commissioners must be satisfactory to the public at large, as demonstrating that for a long period to come British commerce is not likely to languish, or British household fires to smoulder, for want of that prime necessary of British life—COAL.

CHAPTER XXXIV.

COAL SOUTH OF THE THAMES.

WHEN the last edition of this work was published the presence of coal south of the Thames Valley was purely a matter of geological inference; it is now an ascertained fact. From the time in which that distinguished geologist, the late Mr. Godwin-Austen, announced his views in 1855, in his memorable paper read before the Geological Society,* the subject had been a favourite one for discussion amongst geologists, and Godwin-Austen's views were supported by the late Sir Joseph Prestwich in the Report of the Royal Coal Commission of 1871.† The credit, however, of experimentally demonstrating the existence of coal-seams below the Chalk is due to Mr. Francis Brady, Engineer of the Channel Tunnel, under the advice of Prof. Boyd Dawkins, F.R.S., and an experimental boring was commenced in a position at the foot of Shakespeare's Cliff, near Dover, in 1895–6; with the result that the coal-measures were reached at a depth of 1,100 feet below Ordnance datum, and were penetrated through a thickness of 1,174 feet. In this boring 13 seams of coal were passed through, the most important of which was a four-feet

* "Quart. Journ. Geol. Soc.," vol. xii.

† "Report," vol. i, p. 146. In the 4th edit. (1881) of this work, the author indicated on the map, by a dotted line, the probable position of a trough of coal-measures extending from Dover westwards into Wilts, passing by Maidstone, Caterham, and south of Reading.

seam of bituminous coal at a depth of 2,169 feet, having a roof of black shale containing Carboniferous plant remains.* Several other thinner, but workable, seams were also passed through, and the boring terminated in "bind" (shale), the total thickness of the formation not having been ascertained. Other borings followed this successful experiment; one being put down at Ropersole at a spot 8 miles from Dover along the road to Canterbury, in which coal-measures with several thin seams were reached at a depth of 1,580 feet, while another and third boring was made at Ellinge, about 5 miles N.W. of Dover, which was carried down to a depth of 2,129 feet.† In this boring coal-measures were struck at a depth of 1,686 feet from the surface, and dark shales with sandstones of the same formation were penetrated to a depth of 1,815 feet.

A fourth boring was put down at Brabourne, in which dolomitic conglomerate of Triassic age was reached at a depth of 1,875 feet. This rock was found to be 34 feet in thickness and contained pebbles of Carboniferous Limestone and quartz; below this was found either Old Red Sandstone, according to one statement, or "dark-bluish compact slate" according to another, with a dip of 60°.‡

* Prof. W. Boyd Dawkins, Coal-Commission, "Minutes of Evidence," October 22, 1903. The plants are: *Lepidodendron*, *Stigmaria ficoides*, *Carpolites*, etc.

† Details of the above are given by Prof. Dawkins. Valuble evidence on this subject was also given by Mr. William Whitaker, F.R.S., and the late Mr. Etheridge, which is, on the whole, in agreement with that by Prof. Dawkins. Mr. Whitaker's evidence was given on November 24, 1903.

‡ The first is that stated by Prof. Dawkins in his evidence before the Coal Commission, on the authority of Mr. Etheridge; the second is that in my note-book of borings, and is probably the more correct, as indicated by the details of dip, etc. No fossils were found in the slate, which might be of Silurian or Devonian age.

This boring is of great importance, as it shows that the Dover coal-trough does not extend so far in a south-westerly direction as Brabourne. In other words, if we draw the line representing the southern margin of the coal trough from the coast south of Dover inland, we should have to carry it some distance to the north of this site; so that, although the boring was unsuccessful in proving coal, it has been of great service for future investigations, in showing the approximate limits of the unproductive region below the Weald.

Other Borings.—Besides the above, several other borings have been put down from time to time in order to prove the existence of coal, or otherwise; but, unfortunately, they have failed to be carried down to sufficient depth to get below the Mesozoic formations, and thus to prove the character of the subordinate Palæozoic rocks. Of these the borings at Ottinge, Hothfield and Old Soar,* to the north of Tunbridge, have not been carried deep enough to afford any evidence. But the most important and interesting, as being the first in point of time, was that of Netherfield, near Battle, in Sussex, in which the following strata were penetrated:—†

Section at Netherfield.

Formation.	Thickness. Feet.
1. Wealden and Purbeck Beds	180
2. Portland Limestone, etc.	65
3. Kimmeridge Clay	1,524
4. Coralline Oolite	17
5. Oxford Clay	119
Total	1,905

* These were undertaken by the Kent Coal Exploration Company.

† This boring was first suggested by the late Mr. Henry Willett of Brighton

The failure of this boring to prove the nature of the sub-Wealden strata in this part of England was due to the extraordinary and unexpected thickness of the Kimmeridge Clay, which reaches at Netherfield a thickness of 1,524 feet, but which becomes thinner so rapidly northward that at Dover it has only a thickness of 73 feet. Interesting as is the light this boring has thrown on the strata, its negative result in failing to reach the Palæozoic formations must ever be a cause of regret.

Importance of the Dover Coal.—It is unnecessary to insist upon the great importance of the discovery of coal under this part of England; and it is unfortunate that the pioneers in this discovery have not as yet been rewarded by an opportunity of supplying the wants of the district. In 1897 a Company was formed to put down shafts at the site of the boring, but unforeseen obstacles, from the irruption of water and other causes unnecessary to explain here, have retarded their completion, and a coal supply from a Kent mine remains still an object to be accomplished in the not, I should hope, distant future.

From the analysis of the four-feet seam which it is hoped ere long to win, it would appear that the coal is of that class known as semi-bituminous or "steam coal," as it contains 83·8 per cent. of carbon, and it is thus comparable with the coals of this description from South Wales. There is therefore every prospect that the working of this seam will prove of great advantage not only to the town and neighbourhood of Dover, but to the railways of this part of England, and to steamers plying across the Channel and to other ports.

in 1872, and is described by Topley, "Geology of Sussex," 1875, and Woodward, "Monograph of Jurassic Rocks of England," vol. v, p. 345.

It now remains to adduce the evidence in favour of the view of the existence of a second coal-trough in this part of England.

A Probable more Southerly Coal-trough.

Although the coal-trough of Dover may prove to be the more important in the S.E. of England, on account of its extension westward under the Cretaceous strata south of London, as also beneath the bed of the Channel in the opposite direction towards Calais, there are strong grounds for believing that a second and parallel trough exists below the Wealden beds a few miles further south. The ground for this view will now be stated in some detail, as it is one requiring some knowledge of the geological structure of that part of France bordering on the Straits of Dover in the neighbourhood of Boulogne.*

The structure of the country about Boulogne is the key by which to unlock the problem of that of the south of England, and of the presence or absence of Carboniferous strata therein. We have already expressed the opinion that the Dover coal-trough is connected under the Straits with the coal-measures which have been proved by boring to underlie the Pas de Calais at a depth of 1032 feet.† In this boring no coal was proved, and probably the strata were in the horizon of the Millstone Grit series, at the base of the coal-measures, so that the Calais bed may be

* The late Mr. William Topley appears to have held the opinion that there is a second trough of coal-measures under the Weald, as he says, "It is quite possible that a little south of the Bas-Boulonnais there may be a trough of coal-measures which may be prolonged into the Weald." "Mem. Geology of the Weald," p. 349 (1874).

† Prestwich, "Report, Coal Commission of 1870–1," vol. i, p. 133.

"the eastern lip" of the Dover coal-trough. Between these beds and the Bas Boulonnais the Carboniferous Limestone and Old Red Sandstone rise to the surface in the form of a saddle, or anti-clinal, and are visible near Marquise at the base of the ridge of chalk, having a dip to the S.S.W., and striking in the direction of Cap Gris Nez. The limestone passes beneath Jurassic beds, which are nearly horizontal and unconformable; but should the dip of the older formations be continuous, the result would be to introduce a trough of coal-measures in the direction of Boulogne itself.* Such is, briefly, the general structure of the strata on the eastern border of the Straits of Dover, and we have now to consider how it bears upon that of the opposite coast and land of England. The great fact that the general trend of the strata is along great folds ranging in nearly an east and west direction, is abundantly proved as far as the French formations are concerned. The Straits do not in the least affect the course of these great dominant flexures, which may therefore be considered to pass under the submerged area of the Channel—lost indeed to sight by the Cretaceous formations which rest upon the older formations unconformably, but which none the less hold their course on reaching the land area. Guided by the direction of the Dover trough, as proved by the borings above described, we may suppose that the Carboniferous Limestone of Marquise would strike the coast of England at Hythe below the Weald clay; and assuming the same southerly dip to continue, a coal-trough may be presumed to lie under Romney Marsh, and thence to extend westward under Tenterden, Tunbridge Wells and Horsham,

* This inferential coal-trough has been partially proved at Fermes and Hardingen. "Carte Géologique de France," Sheet 3.

and possibly to pass below the chalk towards Salisbury. A general east to west trend of these Carboniferous and Devonian rocks under those of Cretaceous and Jurassic ages through Hants, Wilts and Dorset, may be fairly inferred from what we know of the structure of the rocks on both sides of the Channel; and hence the anticlinal fold of the rocks between the Pas de Calais and Boulogne, known as "the Axis of Artois," * and the uprise of the Carboniferous Limestone and Devonian beds in France, may be regarded as representative of that of the Mendip Hills in Somersetshire.†

The general conclusion is that there exist in all probability, not only one, but two coal-bearing troughs under the south of England: one ranging from Dover westward by Maidstone, Guildford and Devizes towards, but absolutely disconnected from, the Bristol coal-field; the other in a somewhat parallel direction from the coast at Romney Marsh by Tenterden, Tunbridge Wells and under Salisbury Plain towards the vicinity of Glastonbury to the south of the Mendip Hills, under some parts of which a concealed coal-field may with some probability be considered to lie; but up to the present no boring has been carried to sufficient depth to prove the nature of the rocks beneath the Trias, south of the Mendips.‡ If a similar

* The name given by Mr. Godwin-Austen.

† The structure of the Boulogne district and its relations to that of the south of England has been ably treated by M. Marcel Bertrand in his paper "On the Correlation of the Coal-fields of Northern France and Southern England." "Trans. Federated Institute of Mining Engineers" (1893).

‡ The subject of the possible existence of coal south of the Mendips has been ably treated by Mr. W. A. E. Ussher, of the Geological Survey, in a paper read before the "Somersetshire Archæological and Natural History Society" (1891). He recommends as sites for experimental borings High-

amount of enterprise had been called forth in the south of England as has been shown in France and Belgium, many of the problems now awaiting solution would have remained problems no longer.

The following section through the London Basin will be of use in showing the position of the formations.

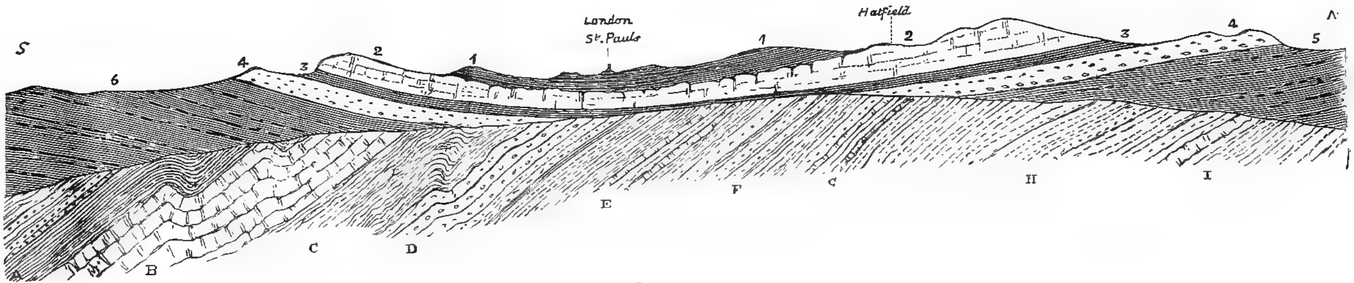
Export of British Coal.

Before proceeding to the description of the coal-fields of foreign countries, it may be well to give a summary of the destinations of the great trade carried on in exporting British coal during 1899 and the three following years. It will be seen that it is an expanding trade, and many persons may have the opinion that it is expanding too rapidly, to the detriment of our coal reserves. The figures have been furnished to the Coal Commission by Mr. D. M. Stevenson.* The quantity exported in 1904 amounted to no less than 46,255,547 tons, as supplied by the Board of Trade returns; this figure is exclusive of "bunkerage," which amounted to 17,190,901 tons exported in the same year.

bridge, Burnham, Berrow, Brent, Chapel Allerton, etc. I may here observe that it is a remarkable circumstance that amongst all the borings south of the Thames Valley none of them have proved the existence of the Carboniferous Limestone, a formation of great thickness and persistency in Belgium and France.

* Table, see p. 291.

Fig. 20.—SECTION NORTH AND SOUTH THROUGH THE LONDON BASIN—SHOWING PROBABLE POSITION OF CONCEALED PALÆOZOIC ROCKS.



EXPLANATION.

A. Middle Carboniferous Beds.
B. Carboniferous Limestone.
C. Carboniferous Slate, etc.
D. Old Red Sandstone (Upper Devonian).
E. Middle Devonian Beds.
F. Lower Devonian Beds.
G. and H. Upper Silurian Beds.
I. Lower Silurian Beds.

1. Tertiary Beds.
2. Chalk and Upper Greensand.
3. Gault Clay.
4. Lower Greensand.
5. Wealden Series.
6. Oolitic or Jurassic Beds.

Length of Section about 65 miles.

TABLE showing the Destination of Coal Exported from the United Kingdom.

Country.	Total, United Kingdom.			
	1899.	1900.	1901.	1902.
	Tons.	Tons.	Tons.	Tons.
Argentine Republic	988,608	768,099	905,129	973,386
Austrian Territories	224,100	144,497	189,663	331,592
Belgium	741,133	1,152,109	738,823	618,559
Brazil	920,414	750,910	776,018	924,114
Canada	38,225	21,730	100,910	123,103
Denmark	2,015,437	2,056,990	2,101,595	2,097,786
Egypt	2,083,783	1,935,832	2,061,223	1,965,929
France	6,646,685	8,314,697	7,565,606	7,408,431
Germany	5,029,515	5,938,178	5,819,844	5,814,477
Holland	1,195,384	1,812,257	1,053,218	743,783
Italy...	5,235,508	5,115,125	5,497,625	5,797,618
Norway	1,374,522	1,342,759	1,273,456	1,345,345
Russia	3,274,274	3,116,099	2,403,425	2,297,693
Spain	1,529,285	1,695,820	1,835,762	1,928,916
Sweden	2,990,641	2,968,579	2,794,978	2,856,849
South Africa, Cape...	472,321	645,586	651,079	697,804
United States ...	119,421	40,145	95,700	836,550
Uruguay	352,324	456,795	451,595	658,217
Other countries ...	5,948,572	5,812,990	5,561,432	5,738,894
Total	41,180,332	44,089,197	41,877,081	43,159,046

The quantity for 1904 is given in p. 289, and amounts to 46,255,547 tons, in addition to which are 17,190,900 tons for consumption on board the ships (bunkerage).

PART III.

CHAPTER I.

COAL-FIELDS OF EUROPE.

BEFORE proceeding to the description of the separate Coal-fields of Europe, it may be desirable to place before the reader, in a tabular form, the representative groups of strata in the British Isles and Europe. This table will show at a glance what members of the great Carboniferous system are present in each country; and it will be observed that, owing to denudation, the uppermost division is generally absent on the continent. As regards the succession of strata, there is evidence of a remarkable resemblance over large areas; a resemblance which is also conspicuous in the case of the organic remains which characterise the formations. The ternary division shown in the table is founded both on physical and palæontological evidence.

France and Belgium.—The Coal-formation of these countries extends in a long and narrow trough from Aix-la-Chapelle westward, by Liége, Namur, Mons, Valenciennes, Douai, and Arras, near which place it is concealed beneath nearly horizontal beds of Cretaceous and Tertiary rocks. West of this town, however, the coal has been proved to a distance of 80 miles, valuable beds

TABLE of Continental Equivalents of British Carboniferous Divisions.*

Divisions.	Stages.	British Equivalents.	France.	Belgium.†	Rhenish Provinces, &c.	Silesia, etc.
UPPER CARBONIFEROUS (essentially estuarine and lacustrine).	G.	Upper Coal-measures.	—	—	—	Coal-measures. "Étage hangende" (Lottner)?
	F.	Middle Coal-measures.	Alais, St. Etienne.	Douai and Hainaut (Bassin de Namur).	Saarbrück, Dortmund, and Westphalian Coal-fields.	Coal-measures. "Étage mittlere" (Lottner).
MIDDLE CARBONIFEROUS (essentially marine).	E.	Gannister beds, etc.	Schistes de Lens, Auchy-au-Bois.	Schistes alunifères de Chokier, de camp de Casteau près Mons.	Dark shales with marine shells (Westphalia) Lower stage (Lottner).	Black shales (schwartze Schieferthon (with marine shells. "Étage liegende" (Lottner).
	D.	Millstone Grit series.	Not recognised.	Schistes des Ampélites?	Flötzleerer Sandstein of Rhenish Prussia.	Lower Sandstones of the Hartz, etc. (Murchison).
	C.	"Yoredale series" of the Geol. Survey.	—	Calcaire de Visé.	Not recognised.	Not recognised.
LOWER CARBONIFEROUS (essentially marine, sometimes lacustrine at base).	B.	Carboniferous limestone.	Calcaire de Lille, Sablé, etc.	Calcaire de Dinant, Tournai, Namur, etc.	Dark limestones and schists with *Posidonomya Becheri*.	Beds of limestone (often absent).
	A.	Lower shales, slates, calciferous sandstones, and conglomerates.	—	Schistes de Tournai.	"Kieselschiefer."	Replaced by older rocks.

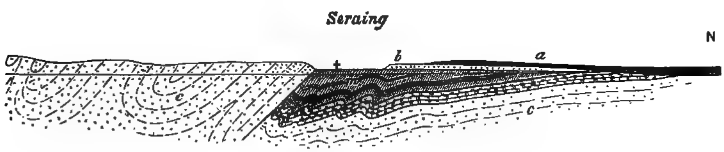
* This table is extracted from my paper on the Classification of the Carboniferous Series, "Quart. Journ. Geol. Soc.," November, 1877, and has been accepted by several continental geologists of eminence. A slight inaccuracy has been corrected at the instance of my friend, Dr. C. Barrois, of Lille.

† To stage E, in the Belgian Series, the second "niveau fossilifère' of MM. Briart and Cornet is referable, with *Productus carbonarius*, *Chonetes Laguessiana*, a *Cardinia*, and *Avicula;* to which Prof. Dewalque has added *Orthis crenistria*, *Posidonomya vetusta* (?), *Goniatites*, *Pecten*, and *Terebratula* ("Bull. de l'Acad. Roy. de Belgique," 2nd sér., t. 33, No. 1, 1872).

having been found at Therouanne; and again they reach the surface a few miles N.E. of Boulogne. Between the coal-field of Valenciennes and Boulogne there is a large upcast fault bringing up the Devonian rocks, so that the Boulogne coal-district is a distinct basin.* Here the dip is north, and the Carboniferous Limestone rises from below the coal-measures. Before entering the sea at Calais, the Carboniferous strata are concealed by Lower Oolite, and nowhere reappear across the south of England till we reach Somersetshire.

The Franco-Belgian coal-trough is not everywhere continuous, being dissevered into elongated basins east of

Fig. 21.—SECTION ACROSS THE COAL-FIELD OF LIÉGE. 18 Miles.†



a, Tertiary Beds. *b*, Cretaceous. *c*, Devonian. N, Carboniferous.

Mons, by the elevation of the Lower Carboniferous rocks. These latter themselves, as in the north of England, sometimes contain coal which has been mistaken for that of the true coal-formation; and at Liége and Mons the strata are repeatedly crumpled, and thrown into a vertically zig-zag position, so that the same shaft passes several times through the same seam of coal. We have analogous cases along the northern flanks of the Mendip Hills in Somersetshire, but not so generally known. The whole length of the

* As I have been informed by M. Louis Aguillon, Mining Engineer.

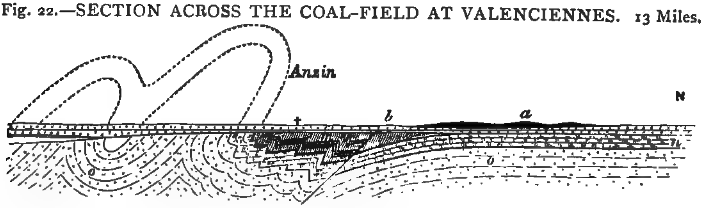
† This and Fig. 22 are taken from a drawing by Mr. Prestwich, F.R.S., in "Report of the Royal Coal Commission."

trough, measured from Aix-la-Chapelle to Calais, and considered as continuous, is about 210 miles; but the breadth is variable, and never great.

The united extent of these coal-fields is probably nearly 1,200 square miles; but there is a considerable tract between Valenciennes and Calais, overspread by Chalk and Tertiary formations, under which the Coal-measures have not yet been proved, and where they lie at considerable depths.* The general arrangement of the strata in this part of their course is shown in the following section (Fig. 22).

I shall now state the names of the towns and villages

Fig. 22.—SECTION ACROSS THE COAL-FIELD AT VALENCIENNES. 13 Miles.



d, Tertiary beds. *b*, Cretaceous. N and M, Lower and Upper Carboniferous.

situated along this trough, from west to east, taking as a guide the map of M. A. Dumont.† Commencing at Lillers in Artois, it ranges by Bethune, Douai, Valenciennes, Condé, Mons, Namur, Huy, Liége, Aix-la-Chapelle—where the strata are folded into several distinct troughs; and about ten miles east of this town the Coal-measures become entirely concealed beneath the alluvial plain of the Rhine. Their course beneath this plain would appear to be N.E.

* MM. Dufrénoy et Elie de Beaumont, "Carte Géologique de la France."

† "Carte Géologique de la Belgique." See also the elaborate maps and sections in the "Atlas zur Geologie der Steinkohlen Deutschlands," von Dr. Geinitz, Munich, 1865.

by Juliers and Kaiserwerth, to the Valley of the Ruhr, at the margin of the coal-field of Westphalia.

The depth of the Liége coal-basin at Mont St. Giles, according to Herr Von Oeynhausen, reaches to 3,809 feet below the surface, and the coal-basin of Mons is fully 1,865 feet deeper still. But this is small in comparison with the depth attained by the strata in the Saarbrück coal-field.

There are also several small coal-fields in France surrounding the central granitic plateau, of which the following are the principal :—

That of St. Etienne, about 15 miles long by 6 broad, yielding about 6 millions of tons of coal annually; the basin of the Saone et Loire; and the basin of Alais, in the department of Gard and Ardèche. There is also the coal-district of Ronchamp in the department of Haute Saône; and the anthracite district in the department of Isère, or the Basin des Drac.*

In 1901 France produced 32,325,302, and Belgium 23,462,817, metric tons of coal.†

Rhenish Provinces of Prussia: the Saarbrück Coal-field.—This is the largest and most important coal-field in western Europe, having an area of about 900 square miles. Along its western borders it is traversed by the River Saar, between the towns of Saarlouis and Saarbrücken, and extends in an easterly direction to Wellesweiller, where the beds pass below the Bunter Sandstone, which stretches along the southern borders of the coal-field, and along the valley of the Saar forms also the western boundary. The

* "Die Steinkohlen Deutschlands," etc., 1 band, cap. xii, 351.

† Returns prepared for the Coal Commission by Mr. Bennett H. Brough.

coal-seams, however, have been worked below this newer formation at intervals all along the margin.*

Towards the north the coal-formation rests upon the Devonian schists of the Hundsrück (the "Koblenzer oder Spirifer-Schichten"), the general dip being southward, in which direction the coal-measures pass below the Permian beds and New Red Sandstone of the Vosges. There are extensive intrusions of igneous rocks, especially along the northern outcrop, which detract from the mineral value of the district affected by them.

According to the observations of Herr von Dechen,† the thickness and depth of the coal-measures in the Saarbrück basin is very great. From several measurements it was found that the lowest coal-strata known in the district of Duttweiler, near Bettingen, descend to a depth of 20,682 English feet, or 3·6 geographical miles below the level of the sea. This is a depth below the sea equal to the height of Chimborazo above it; and at this depth the temperature may be inferred to range as high as 467° Fahr.

This coal-field is remarkable for having yielded the remains of several species of reptiles, discovered by Leonard Horner, and named by Prof. Goldfuss *Archegosaurus*, having characters intermediate between the Batrachians and Saurians.‡ There are also fish of the genera *Amblypterus*, *Palæoniscus*, *Acanthodes;* Crustacea, as *Uronectes Estheria tenella*, *Leaia Bantschiana;* and Molluscs, *Unio*

* See the admirable chart and description of this coal-field by H. von Rönne, Royal Inspector of Mines, in "Die Steinkohlen Deutschlands," vols. i and ii.

† Geognostische Umrisse der Rheinlander zwischen Basel und Mainz, etc., "v. Herren v. Oeynhausen, v. Dechen, und v. La Roche" (1825).

‡ Geinitz, "Steinkohlen," vol. i, 150.

carbonarius (Bronn), *U. Kirnensis* (Ldwg.). The plant remains are abundant, and amongst others include the more common Carboniferous genera, such as *Lepidodendron*, *Sigillaria*, with *Stigmaria, ficoides*, *Ulodendron*, etc.*

The Coal-fields of the Kingdom of Saxony.—The coal-formation of Saxony is distributed into a series of beds which, collectively, may be regarded as a representative series of the formation in Germany. Dr. Geinitz distinguishes in it five successive zones of vegetation, which have appeared at intervals during a long lapse of time.

The Coal-basin of Zwickau-Chemnitz.—This coal-field lies to the north of the Erz Gebirge, the range of mountains which forms the southern border of Saxony, and extends from the village of Marienthal, west of Zwickau, on the S.W. to Liegmar, near Chemnitz, on the N.E., a distance of 4 geographical miles. Along the south the Carboniferous beds repose on Silurian and Devonian rocks.† Towards the north they are overlaid unconformably by a massive conglomerate with pebbles of quartz, schist, and granite; and this by other beds of sandstone, shale, and porphyry, referable to the Permian series (Rothliegende).

The coal-field contains about 12 seams of workable coal, one of which, the "Russkohlflötz," is 12 ells in thickness.‡

Plant-remains.—The lowest beds are characterised by *Sigillaria alternans*, *S. oculata*, *S. Cortei*, etc., *Sagenaria dichotoma*, *Neuropteris auriculata*, *Asterophyllites foliosus*, etc. Above this is the "Annularian Zone," with *A. longifolia*, *Sphenophyllum emarginatum*; next the "Zone der Farren," (or Zone of Ferns), with *Sphenopteris irregularis*, *Sph.*

* A complete list is given by Dr. Geinitz in the work quoted.

† "Geognostische Karte von Sachsen," section xv.

‡ "Die Steinkohlen Deutschlands, vol. i, p. 56.

Macilenta, *Odontopteris Reichiana*, *Neuropteris auriculata*, etc., *Lycopodites Gutbieri*, *Næggerathia palmæformis*.

Coal-basin of the Plauenscher Grund, near Dresden.—This coal-field is traversed by the Weisseritz, a short distance above Dresden, and has its longest diameter of 1½ geographical mile, in a N.W. and S.E. direction, at right angles to the course of that stream.

The Coal-measures rest upon an irregular basis of syenite, porphyry, and (at the "Augustus" colliery) of clay slate, against a shelving bank of which the coal-seams terminate in a S.W. direction. The formation is overlaid by the conglomerate base of the Rothliegende, which is succeeded by higher divisions of the Permian series.

The coal is condensed almost into one principal and very thick seam, which is much broken by faults, and subjected to irregularities of dip and horizontal extension. The plant remains are similar to those already described for the Zwickau-basin.*

Saxony contains, besides the above, Culm-measures at Ebersdorf; anthracite in the Upper Erzgebirge, and a small coal-field at Flöha and Gückelsberg.

Westphalia.—This coal-field extends from the right bank of the Rhine at Duisburg and Ruhrort, at its junction with the Ruhr, and extends along both banks of that river as far as Herdecke and Wetter, in an easterly direction, a distance of about 46 miles. The strata belong to the Carboniferous system, reposing on beds of Millstone Grit (Flötzleerer sandstein), which in turn overlie Carboniferous Limestone and Culm-measures; the limestone, however,

* Map and section of this coal-field, by Dr. Geinitz.—"Die Steink. Deutsch.," Plates III and IV.

thins away eastward.* Towards the north, the Coal-measures pass below Cretaceous strata (Kreidemergel), which rest unconformably on the convoluted edges of the Carboniferous rocks.

Recently, as shown by evidence brought before the Coal Commission, the output of coal from Westphalia has received a great impulse, owing to its good qualities and facilities for transit.

The Coal-measures have been bent into a great number of remarkably regular folds, not very sharp, and with their axes ranging in an average direction of E. 25° N. The consequence of this structure is, that the coal-seams are arranged in a series of narrow troughs, from thirteen to fifteen in number, when counted across the centre of the field. These flexures, on the whole, dip very gradually towards the E.N.E., and rise in the direction of the Rhine Valley, where they terminate; so that at Ruhrort the coal-field is contracted to a narrow band. That it crosses under the river, and underlies the town of Meurs, there can be little doubt. The flexures I have described are clearly referable to the same system as those which have bent and folded the coal-seams of Belgium and the North of France.†

Coal-field of Ibbenbüren, N.W. Germany, examined and described by Herren Heine and Dortmond,‡ belongs to the Carboniferous formation, with *Calamites*, *Sigillaria*, *Sphenopteris*, *Neuropteris*, etc. The Coal-measures, with

* The Culm-shales contain *Posidonia Becheri*.—"Siluria," 3rd edit., p. 427.

† For map, sections, and description of this coal-field, the reader is referred to "Die Steinkohlen Deutschlands," etc., vols. i and ii.

‡ "Zeitschrift der Deutschen Geolog. Ges.," Berlin, 1861.

five workable coal-seams, are overlaid by Zechstein (Permian Limestone) and Triassic strata, along their southern borders.

Coal-field of Piesberg, near Osnabrück, in Hanover.—This coal-field, though now separated from that of Ibbenbüren, seems once to have been continuous with it; some of the seams of coal having been identified by Herr v. Velsen. The strata consist largely of sandstone and conglomerate, with nine coal-seams, amongst which Prof. von Römer has identified a large number of plants of the Carboniferous species, including the root-stalk *Stigmaria ficoides*, *Sigillaria striata*, *Lepidodendron dichotomum*, *L. elegans*, *Alethopteris pteroides*, *Sphenopteris gracilis*, *S. nervosa*, *Calamites Suckovii*, etc.*

Bohemia.—According to the accounts of M. Michel Chevalier, nature has left to Bohemia a rich dowry of mineral fuel. Besides the older coal-bearing strata, there are very extensive areas underlaid by lignite of excellent quality, now worked in the north-western districts.

M. Chevalier considers that the coal-formation belongs to two different ages, that of Eastern Bohemia to the Lower Permian or Roche-todte-liegende; that of Western to the true Carboniferous system. The former extends in a band along the base of the Chaîne des Géants (Riesen Gebirge). This band is probably connected with the coal-formation of Silesia.

The western formation is distributed into three basins. 1st, that of Rakonitz; 2nd, that of Radnitz; 3rd, that of Pilsen. Of these, the basin of Rakonitz is the most extensive.

* "Die Steinkohlen Deutsch.," Band i, 201.

The flora of Rakonitz and Radnitz, described by M. Stur and Count C. Sternberg respectively, consist of about 21 genera of Carboniferous plants.

The Weald Coal-formation of North-west Germany.—In Hanover and N.W. Germany there occurs a great series of beds attaining a thickness of about 2,000 feet, which, according to the researches of Herr Credner, are referable to five stages—

1. *Wälderthow* (with *Melania*), representing the Weald Clay of England.
2. *Wäldersandstein* (or Deister Sandstein), representing the Hastings Sand of England.

3. *Serpulit*, limestones and shales...	Representing the Purbeck Beds of England.
4. *Mündermergel*, marl and dolomite	
5. *Plattenkalk*, with *Corbula inflexa*	

These beds are underlaid by the Jurassic formation (Weisser und Brauner Jura), and dip beneath Neocomian and Chalk strata, and are traversed by the rivers Vechte, Ems, Haase, and Weser, near Minden, and from thence extend in an interrupted band nearly to the bank of the Leine, south of Hanover.

The greater number of coal-seams occur in the upper member of the group (Weald Clay), the section at Deister showing about 15 seams of coal, of which the greater number, however, are impure.

Silesia.—This coal-field is very extensive. It stretches from the eastern base of the Riesengebirge, at Bober and Schatzlar, in a semicircle by Landschut, Gottesberg, Waldenberg, and Tannhausen, to Eckersdorf, near the banks of the river Neisse. The Coal-measures have, in general, a base of Carboniferous Limestone, except towards the eastern portion, where they repose directly upon gneissose strata. They in turn are overlaid by Lower

Permian (Rothliegende) and Cretaceous formations, and are often invaded by masses of porphyry and other igneous rocks.*

The coal-formation contains several valuable seams of coal, worked in several localities, as at the collieries of Louise, Gustav, Emili, Morgen und Abendstern, Finstern, Frans-Joseph, and Segen-Gottes, Friedrich Wilhelm, and many others.

On the organic remains of this coal-field the writings of Dr. H. R. Göppert have thrown much light. This observer arranges the formation into zones characterised by special plants, such as *Stigmaria*, *Sagenaria*, and *Lycopodacea;* which Dr. Geinitz endeavours to identify with certain stages in the Coal-measures of Saxony. The usual Carboniferous genera of *Sigillaria*, *Stigmaria* (root) *Nœggerathia*, etc., are here well represented.

Bohemia also contains extensive areas underlaid by lignite of excellent quality.

Prussian and Austrian Silesia.—This coal-field lies on the borders of Poland, being traversed by the river Weichsel. The strata are referable to the Carboniferous system, and coal is extensively worked between Beuthen and Kostow.

In 1901 the output of Germany amounted to 153,019,414 metric tons of coal.†

Moravia.—The coal-field of Eastern Moravia lies along the banks of the Oder, and its tributary the Ostrawitza, for some distance upwards from their confluence; and mining operations are extensively carried on at Koblan,

* See map and description of this coal-field in vols. i and ii of "Die Steinkohlen Deutschlands"; also Murchison's "Siluria," p. 391–2.

† Mr. Bennett H. Brough, "Report Coal Commission," 1904.

Hruschau, Petrzkowitz, Ostran, Muglinan, Michalkowitz, and Hranecznik. In this district Baron Rothschild has both coal-mines and iron-works.

The coal-seams, one of which (Adolph-Flötz) is about 25 feet in thickness, are included in the Upper Carboniferous series, and repose upon Flötzleerer Sandstein (Millstone Grit), Posidonomya shale, and Carboniferous Limestone.

Another coal-district is that of Rossitz and Oslawan, extending for several miles in a nearly north and south direction, and bounded on the west by gneiss, and on the east by syenite. The base of the formation is here a red conglomerate resting on the gneiss, and the Carboniferous rocks are overlaid towards the east by strata referable to the Permian formation (Unteres Rothliegendes).*

Hungary.—There are small coal-fields in several parts of Hungary belonging to the Secondary and Tertiary periods.

Of the former are those of Oravitza, of Berzaska, and Eibenthal, near the northern banks of the Lower Danube; and Peterwardein and Fumfkirchen near Pest. The coal from these places is a kind of semi-anthracite belonging to the Lias formation.

The coal of Gran, north of Buda-Pesth, is of Tertiary age, and is of the variety known as "brown coal."

At Eibenthal there are several seams, one of which is 20 feet in thickness. The strata are in a nearly vertical position, and crop out along the sides of the wooded valleys. There is abundance of coal in Hungary for the

* "Die Steinkohlen Deutschlands," etc., vol. i, chap. viii.

supply of the railways and steamers on the Danube, besides the manufacturing and domestic uses now annually increasing.

The output of coal in Austria-Hungary for the year 1901 amounted to 40,757,895 metric tons.

Spain.—The coal-field of Asturias, in the valley of Quiros, is one of great economic value, though as yet only partially developed. It lies a short distance to the south of Oviedo, and has an area of about 14,826 acres.* The strata containing the beds of coal belong to the Carboniferous system and repose upon Carboniferous limestone, which rises into a high range of hills to the N.E., E., and S. The beds are thrown into high angles varying from 50° to 70°, and strike in approximately north and south directions. Towards the south, the hilly nature of the ground, and the deep valleys by which it is intersected, offer great facilities for economic working of the coal by means of adits. There are fifty distinct workable seams from 16 inches to 6 feet in thickness; and the coals belong to three classes, viz., anthracite, semi-bituminous, and bituminous.

M. D'Orbigny states that the thickness of the coal-formation of Asturias is 4,000 mètres; and in the lower part consists of alternating beds of coal and marine strata.† M. Charles Barrois, of Lille, has recognised similar divisions to those of France and of England, including representatives of the "Gannister Beds," with *Anthracosia*, *Bellerophon*, etc. Fossil plants of the genera

* "Report on the Coal-field," by G. Heim (1860), for an inspection of which I am indebted to Prof. O'Reilly, M.R.I.A. This report gives full and elaborate details of the minerals of the district.

† "Cours Élém. de Palæont.," p. 343.

Calamites, *Sigillaria*, with the root (*Stigmaria*), and *Neuropteris heterofilia* (Brong.), have been recognised.*

M. Shultz, Director-General of Mines, states that the coal-basin of the centre of the Asturias forms a most extensive district, having more than 60 seams of coal, generally of the best quality, approaching to a vertical position, and extending several leagues from west to east. The eastern limit of the coal-tract appears to be Santander; and westward, probably Oviedo. The strike of the rocks is parallel to the axis of the Pyrenees; and near the eastern extremity of the range, on the southern flanks north of Ripoll, coal is extracted from beds which would appear to be an extension of those which yield that mineral in Asturias.

In Eastern Spain there are also important coal-fields in the provinces of Teruel and Castellon de la Plana, and smaller tracts in the valley of the Guadaloupe and in Catalonia. In the province of Teruel they form three productive coal-fields, the strata attaining a thickness of more than 1,600 feet, as shown by M. Coquand.† There are ten beds of workable coal, lignite and jet, which are all being worked to some extent. The whole of the series has been shown to belong to the Lower Cretaceous system, at the base of the Neocomian, and is identified by Prof. J. W. Judd with certain strata occurring at Punfield Cove, in the Isle of Purbeck, and by him termed the "Punfield formation.‡

* Heim, *supra cit.*

† Bull., "Soc. Géol. de France," 2 sér., t. xxiv, p. 144 (1868). See also "Carte Géol. d. l'Espagne et du Portugal, par MM. De Verneuil et Collomb," 1864.

‡ "Quart. Journ. Geol. Soc.," vol. xxvii, p. 207 (1871).

The output of coal in Spain in 1901 amounted to 2,747,724 metric tons. (B. H. Brough.)

Russia.—The coal-fields of Russia are considered by Sir R. I. Murchison to belong to the Lower Carboniferous period.* They are included in a set of strata which has a very extensive range, but is only at intervals productive of valuable coal-beds. These Carboniferous rocks form a narrow band along the western base of the Ural Mountains, from the Arctic Sea to lat. 51° S., plunging generally at high angles towards the west, and containing coal, here associated with sandstones, representing probably the "Millstone Grit" of England. On reaching the river Ural, they are concealed beneath the Permian formation, which laps over their edges; but they reappear again in Central Russia, occupying large areas in the governments of Riazan and Moscow, and stretching northwards to the White Sea, a distance of nearly 900 miles. Throughout this region they are only locally productive.

I am indebted to M. Louis Aguillon for the following account of the distribution of the Russian coal-tracts:—

1. *Central Russia.*—Governments of Tould, Kaluga, Rjasan, and Moscow.

Carboniferous Limestone formation.	White Limestone with *Spirifer Mosquensis.* Yellow Limestone with *Productus gigas*, *P. costatus*, and fish remains. Sandstones and shales with coal-seams.

2. *Southern Russia.*—Basin of the Donetz, and the territory of the Don Cossacks. Coal-seams in sandstones and shales subordinate to the Mountain Limestone ("Calcaire de Montagne"); but there may also be beds of true coal-measures in the district.

3. *Siberia.*—Great basin of Kousnetsk in the Altai. Coal-measures with beds of coal.

* "Russia and the Ural Mountains," vol. i, p. 69.

4. *Caucasus* (Txwibul).—Coal in strata subordinate to the Jurassic formation (terrain Oolithique).
5. *Oural.*—Districts of Swewolosky and Lasareff. *c*, Limestone with *Spirifer*; *b*, sandstone and shale with coal; *a*, sandstone with *Productus*.

The coal-seams of the Moscow-basin are generally impure, pyritous, and fragile, and seldom equal in quality to the best lignites of the Tertiary age in the Alps. Some of the seams are from 3 to 6 feet in thickness, and, as they outcrop in natural ravines, are easily accessible. The coal-field between the Dnieper and the Don, north of the Sea of Azof, is considered by Sir R. Murchison to be by far the most valuable in Russia.* This tract has a length from W.N.W. to E.S.E. of 230 miles, and its transverse diameter is 100 miles. Its total area is about 11,000 square miles. It contains many valuable beds of coal, which dip under, and are overspread to the N.E. by, Cretaceous rocks, and to the S.W. by Permian limestone (Zechstein), under both of which formations the coal may at some day be mined, as is the case in Belgium and England. The most valuable seams occur at Lugan and Lissitchia-Balka.

It is a most remarkable circumstance in connection with the Donetz formation, that the same beds of coal, from being highly bituminous in the western parts of this coal-field, pass by imperceptible gradations into anthracite in the eastern parts, in a manner analogous to that of the South Wales coal-field in our own country. In the western or bituminous districts the coals are associated with

* An excellent map of this coal-field, exhibited at South Kensington in 1876, has been constructed by General C. v. Helmersen, showing the coal-seams and numerous flexures.

limestones containing *Spirifer Mosquensis.* Towards the centre these calcareous beds tail out, and are replaced by beds of sandstone and shale, which become hardened and altered as the coal-seams become anthracitic.

On the whole, it would appear from the copious details and sections contained in the elaborate work of Murchison and his companions, that the coal-fields of the Russian empire, certainly of enormous area, are in some parts highly productive, and, if vigorously opened up, are likely to become of great economic value. The whole coal-producing series also appears to be of an earlier date than the true Coal-measures of England; the greater part of the beds of coal being contained in the Carboniferous Limestone series.

The output of coal in Russia for the year 1901 amounted to 16,151,557 metric tons. (B. H. Brough.)

Anthracite of Switzerland, Savoy, and Italy.—Dr. Oswald Heer has described the anthraxiferous deposits, which are worked to a considerable extent as fuel for locomotives of the Italian and Swiss railways. They occur amongst the Western Alps, including towards the west and south the valleys stretching through Savoy into Dauphiné; and in an easterly direction into the Canton of Glarus.*

The anthracite is associated with schists and sandstones containing plant remains of true Carboniferous genera; and an examination of these has convinced Prof. Geinitz that the anthracite beds are an altered Carboniferous product, contrary to the opinion of some observers, who have referred them to the Lias formation, on the ground of their being immediately overlaid (or underlaid by inversion) by shales with belemnites. The presence,

* "Urwelt der Schweiz," 1865.

however, of such examples as *Calamites cannæformis*, *C. Suckowii*, *Asterophyllites equisetiformis*, etc., seems to place their Carboniferous affinities beyond question.*

Similar deposits with anthracite occur in considerable force at Demonte, in the valley of the Stura, in the Alps of Piedmont, consisting of schists with Carboniferous ferns and *Lepidodendron*. They have been described by Chevalier W. P. Jervis, who regards them as likely to prove of great economic value to the young kingdom of Italy.†

Poland.—At the south-western extremity of Poland, and within a short distance of the confines of the Russian, Austrian, and Prussian States, is situated a small but extremely productive coal-field. It contains three known coal-seams, the middle one of which is no less than 16 yards in thickness, and is probably the thickest bed of mineral fuel in Europe. It is worked from the outcrop in mines near the village of Dombrowa, and has the following composition :—

Carbon	50·38
Volatile matter	47·23
Ashes	2·39
Total	100·00

This coal-seam dips from the outcrop at an angle of from 12° to 32°.

The two remaining seams vary from 3 to 9 feet in thickness, and differ from the main seam in having a smaller percentage of volatile matter.

The area of the coal-field is supposed to be about 16 square miles. The formation belongs to the true

* "Die Steink. Deutsch.," vol. i, 340.

† "Mining Journal," August, 1875.

Carboniferous period, reposing on Silurian rocks, and dipping under Tertiary strata.*

Output of European Coal-fields in the year 1901.—The output for the above year in all the coal-producing States of the Continent amounted to (approximately) 535,915,000 tons. The details for each country are given in the table, p. 383, with the description of each: for France, p. 296; for Germany, p. 303; for Austria-Hungary, p. 305; for Spain, p. 307; for Russia, p. 309.

* For this account of the coal-field of Poland I am ndebted to Captain A. Antipoff, of the Russian Engineers.

CHAPTER II.

INDIA.

THE approach towards completion of the surveys of the coal-fields of India by the Government Geological Surveyors, under the late Dr. Oldham, and his successor, Mr. H. B. Medlicott, and the publication of an able series of reports to accompany the maps on which the details are portrayed, puts us in possession of accurate information regarding each coal-field individually.

More recently, an important "Report on the Coal-supply of India" has been drawn up by Prof. W. R. Dunstan, F.R.S., issued in 1898, furnishes us with information of the most recent details concerning the output, character, and composition of the Indian Coal-fields. To this Report I shall have frequent occasion to refer.*

The general result of these surveys is to show that there are very large tracts stored with coal in Northern India, chiefly in the valley of the River Damuda; which, as the Messrs. Blanford† have suggested, were once connected in one continuous area, but are now dissevered, owing to large displacements of the strata and denudation. Of these the names and approximate areas are given in pp. 316, 317.

* The "Report" is printed by order of the Secretary of State for India, and contains maps, diagrams, and analyses of samples of Indian coal.

† "Report on the Talcheer Coal-field," "Mem. Geol. Surv., India," vol. i, Part I.

The coal-beds of India are chiefly found in that great series of conglomerates, sandstones, and shales now comprehended under the name of "the Gondwana System," and the following is the classification of this group as at present recognised by the Geological Survey of India :—*

			Thickness. Feet.
MESOZOIC	Upper	Cutch and Jabalpur ... ... Rajmehal and Mahadeva	11,000
PALÆOZOIC	Lower	Panchet ... ... Damuda ; Ranigunj or Kamthi ... Ironstone Shales and Barakar ... Kaharbari and Talchir	13,000

Geological Age.—The geological age of the coal-bearing formations of India has for many years been a subject of controversy. The subject has been ably discussed by the late Dr. Oldham, on the evidence which had come to light at the time he wrote.†

Having shown that the Upper Damuda, or Rajmahal Group, characterised by the abundance of Cycads, and comparable with the coal-formation of Cutch, is in all probability referable to the "Older Mesozoic Period," he next discusses the relations of these beds to the underlying Damuda Group containing the beds of coal, and shows that, while there is a complete break or unconformity between the two groups, there is also a remarkable change in their respective floras, and an entire absence of

* For the information here given I am largely indebted to Messrs. Medlicott and Blanford's "Manual on the Geology of India," and to a paper "On the Coal-fields and Coal-production of India," by the late Mr. V. Ball, of the Geological Survey of India, published in the Scientific Proceedings of the Royal Dublin Society, 1880.

† "Mem. Géol. Surv., India," vol. ii, p. 298.

Cycads so abundant in the overlying group. The following are the genera determined from the Damuba coal-formation :—

	Species.
Sphenophyllum	3
Vertebraria	2
Phyllotheca	2
Cyclopteris (?)	1
Pecopteris	4
Glossopteris	5 (?)
Calamites	1
Schizoneura	2

After comparing this flora with that of the coal-formation of New South Wales, he finally comes to the conclusion that the Damuda Series belongs to some portion of the Upper Palæozoic epoch of European geological sequence, or the lowest portion of the Mesozoic Division. In fact, according to Dr. Oldham, we may possibly find hereafter that it represents that great interval indicated by the marked separation and hiatus between the two series in other countries.*

On the other hand, more recent investigations have shown that *Glossopteris*, the genus of ferns which had formerly been supposed to be characteristic of the Lower Gondwana Beds, has been found to occur in the very highest beds of the Upper Series—the Jabalpur Beds ; while several species of Cycadaceous plants, which order was supposed to be restricted to the Upper Groups, have been since found to exist in the Lower or Damuda Group ; thus to a great extent, and as far as the flora is concerned,

* *Ibid.*, p. 333. Dr. Oldham stated in 1874 to myself that he adhered to these views.—E. H.

the whole Gondwana system seems to be united into one, notwithstanding physical discordances.

But the difficulties do not end here; for as regards some of the newer groups, the marine faunas, where present, do not always point to the same conclusions as the floras. The matter has been thus summarised by Mr. H. B. Medlicott, in his Annual Report for 1876:—

"The facts of our Gondwana Rocks are certainly puzzling to systematists. On the west, in Kach we have the flora of the Top Gondwana Group, which has a Bathonien *facies* associated with marine fossils of Tithonien affinities; while on the S.E., the Trichinopoli Beds, with a *flora*, so far as known, like that of the Rajmahal Group, which is taken to be Liassic, have been described by Mr. H. Blanford as overlaid in very close relation by the Otatoour Group, the *fauna* of which has been declared upon very full evidence to have a Cenomanien (Upper Cretaceous) *facies*."

From the above it will be apparent that any attempt to correlate the ages of the great coal-bearing rocks with those of Europe and Britain must be considered futile. This great group of lacustrine and fluviatile beds appears to have been formed under geographical conditions entirely dissimilar to those which prevailed in the more westerly regions of the northern hemisphere, and we may rest content with the view adopted by the Authors of the "Manual of the Geology of India," that the whole series of beds from the Talchir Boulder Beds to the Umia Beds of Kach (Cutch) have been deposited during a period ranging from the Permian to the Upper Jurassic of Europe.*

* Dr. Feistmantel, Palæontologist to the Geological Survey of India,

Areas of the Gondwana Rocks.—The following estimates of areas of the coal-bearing beds, and those which may be considered to overlie coal-bearing beds, has been drawn up by Mr. Hughes, of the Indian Survey:—*

	Square miles.
Godavari and affluents	11,000
Sone	8,000
Sirguja and Orissa, etc....	4,500
Assam	3,000
Narbuda and affluents	3,500
Damuda	2,000
Rajmahal area	300
Unsurveyed, etc.	2,700
Total	35,000

List of Separate Coal-fields.

(THOSE IN CAPITALS ARE WORKED.)

Bengal.

1.	Rajmahal Hills	North of Damuda River.
2.	Birbhum	
3.	Deogurh	
4.	KARHARBARI	
5.	RANIGUNJ	Damuda Valley.
6.	Jeriah	
7.	Bokaro	
8.	Ramgurh	
9.	Karanpura, North	
10.	Karanpura, South	
11.	Chope	West of Damuda Valley.
12.	Itkuri	
13.	Aurunga	
14.	Hutar	
15.	DALTONGUNJ	

regards the age as ranging from the Trias to the Lower Oolite or Jurassic; the Cutch Beds being of this latter age.

* "Records," vol. vi, p. 65.

16. Tattapani	Sone and Mahanadi Valleys.
17. South Rewah and Sohagpur	
18. Jhilmilli	
19. Bisrampur	
20. Lukanpur	
21. Rampur	
22. Raigurh and Hingir ...	
23. Udaipur and Korba ...	
Orissá.	
24. Talchir	

Central Provinces.

25. MOPANI	Satpura Region.
26. Tawa	
27. Pench	
28. Bandar	Godaveri Valley.
29. WARDHA or Chanda ...	
30. Kamaram	
31. Singareni	

Sikkim.

32. Sikkim.

Assam.

33. Makum	Valley of the Bhramaputra.
34. Jaipur	
35. Nazira	
36. Jangi	
37. Disai	

In the above list, localities, chiefly situated in the north-west provinces where Tertiary coal occurs, but not in sufficient quantity to constitute workable coal-fields, have not been included.

Of the thirty-seven separate fields, only five are at present worked with regularity. These are Ranigunj,

Karharbari, and Daltongunj in Bengal, and Mopani and Wardah in the Central Provinces.

The output of coal from the Indian coal-fields in 1901 amounted to 6,742,214 metric tons.

I now proceed to give a short description of the more important coal-fields, referring the reader for fuller information to the works already quoted.

RANIGUNJ.*

This field is situated on the rocky frontier of Western Bengal, at a distance of 120 miles from Calcutta.

The groups represented, with their respective thicknesses, are as follows:—

	Feet.
Upper Panchet or Mahadeva	500
Panchet	1,500
Ranigunj	5,000
Ironstone shale	1,400
Barakar	2,000
Talchir	800
Total	11,200

The Ranigunj Coal-field is the largest and most important of the areas in which coal is worked in India. Its proximity to the main line of railway, and also to the Port of Calcutta, tends to give it pre-eminence over other less favourably situated localities. The total area of coal-bearing rocks which is exposed is about 500 square miles; but it is possible that the real area may be even double, since on the east the rocks dip under, and are completely concealed by, alluvium. Throughout this area a central zone includes the principal mines, and the chimneys

* Blanford, "Memoirs Geol. Surv. of India," vol. ii.

which dot this tract constitute it "the black country" of India. In the year 1774 coal was known to occur there; and so long ago as 1777 was actually worked. In 1830 several collieries of considerable extent had been opened out, and were, we have reason to believe, in a flourishing condition.

In 1872 forty-four mines were at work, nineteen of which turned out upwards of 10,000 tons each yearly. In 1879 there were six principal European companies engaged in the extraction of coal, while many minor firms and native associations contributed to swell the amount raised. Many of the seams are of considerable thickness; one being worked reaching 40 feet of coal. As a rule, the thick seams do not contain the best coal. Compared with ordinary British coal, those of India are inferior in working power; still they are capable of generating steam for locomotive and other engines. In 1868 the output from the Ranigunj Mines was 564,933 tons; in 1872 it fell to 322,443 tons; but, as we learn from the speech of the Lieutenant-Governor of Bengal, the quantity raised in 1879 amounted to 523,097 tons.

The coal, which is fairly representative of Indian coals, may be described as non-caking, bituminous, and composed of alternating laminæ of bright jetty and dull earthy appearance. The average of thirty-one assays of samples from different mines has given the following results:—*

Moisture	4·80
Volatile matter	25·83
Carbon (fixed)	53·20
Ash	16·17
Total	100·00

* "Records, Geol. Surv., Ind.," vol. i, p. 155.

The cost of steam coal at the pit's mouth is from $2\frac{1}{2}$ to 3 rupees, say 5*s.* to 6*s.*, per ton. In Calcutta the cost is 14*s.* to 16*s.*, and in Lahore about £5.*

North Karanpura Coal-field.—This coal-field is situated at the head of the Damuda Valley, between 84° 51′ and 85° 30′ E. longitude, and 23° 37′ and 23° 57′ latitude, and covers an area of 472 square miles. From the Report of Mr. T. H. Hughes,† of the Indian Survey, it appears that there are numerous seams of coal, giving a total vertical thickness of 35 feet; calculated to yield about 8,750 millions of tons. A specimen from the larger of the Gondalpura seams gave, on being assayed, the following results:—

Carbon...	64·5
Volatile matter	27·0
Ash	8·5

South Karanpura Coal-field.—This has an area of about 72 square miles, and a thickness of 70 feet of coal, with an estimated quantity of 75,000,000 tons.

The situation of these coal-fields, in a deep valley surrounded by hills, renders it improbable that the ample resources of this district will become fully utilised. Iron ores are abundant.

Aurunga.—This field is situated in the district of Lohardugga, to the west of the sources of the Damuda, in the valley of the Koel, a tributary of the Sone. The area is 97 square miles, and the groups represented are:—

* Mr. V. Ball, *supra cit.*

† "Mem. Geol. Surv., India," vol. ii, Part III, with map.

	Thickness of strata. Feet.
Mahadeva	1,000
Panchet	700
Ranigunj	1,000
Barakar	1,500
Talchir	300
Total	4,500

There are numerous coal-seams, some of good thickness; the estimated amount of coal which they contain being 20,000,000 tons.

The following average proportions of constituents derived from the assays of seven samples from different localities indicate a very poor quality of fuel :—

Moisture	6·7
Volatile	29·3
Carbon	36·5
Ash	27·5
Total	100·0

Valuable and extensive deposits of iron ores and limestones occur in, and near, the coal-field. The inferiority of the coal is to be lamented, as should a project for manufacturing iron in this district ever be adopted, fuel, it seems probable, will have to be obtained from some of the neighbouring fields.

Bokaro Coal-field.—This is the third in importance amongst the coal-tracts of the Damuda Valley. From Mr. T. W. Hughes' Report we find that it contains several seams of valuable coal from the "Barakar Beds," capable of yielding about 1,500 millions of tons. The most valuable portion of this field lies between the River

Koonar and the eastern boundary. Beds of ironstone are also present.*

Jeriah Coal-field.—This tract lies about 170 miles from Calcutta, along the Damuda Valley, and extends from east to west for a distance of 18 miles; its greatest breadth is 10 miles. Mr. Hughes, in his Report, states† that in a series of beds of about 6,000 feet in thickness, there are beds of coal having a combined thickness of about 80 or 100 feet, the thicker seams being in the lower part of the Damuda series. Some of the coal is of good quality, especially that of the "Barakar Beds." The coal is generally capable of yielding a good coke. Dr. Oldham estimates the possible yield of this coal-field at 465 millions of tons, and adds, "whatever the margin of error may be, the facts are sufficient to prove the existence of a very large amount of good fuel in this Jeriah coal-field, which at some future period will be found most valuable."‡

Ramgurh Coal-field.—This coal-field also lies in the Damuda Valley, between the meridian of 85° 30′ and 85° 45′ E. long. From the Report of Mr. V. Ball, it appears to have an area of about 40 square miles. The coal in the eastern part of the district occurs generally in thick seams; but the quality is so variable, and there are such frequent alternations with bands of stony shale, that Mr. Ball forms a low estimate of the economic value of this portion. In the western extension of the field, where the seams are of better quality, they are much broken and crushed, owing to numerous faults and flexures of the strata.§

* "Mem. Geol. Surv., India," vol. vi, Part II.

† *Ibid.*, vol. v, p. 230.

‡ *Ibid.*, vol. v, p. 336.

§ *Ibid.*, vol. vi, Part II.

Karharbari Coal-field.—This coal-field is one of those which lie beyond the limits of the valley of the Damuda. The coal-beds are, however, referable to the "Damuda series," and from the superiority of their quality, and owing to their position with reference to the East Indian Railway and the large towns west of Dinapore, are likely to become of great economic value. The area of the field is only eight square miles, and its general structure that of a basin;* while some of the coal-seams reach a thickness of 14 to 16 feet, but vary rapidly in this respect. Mr. Hughes estimates the yield of this tract at 80 millions of tons of available coal.

The Deoghur Coal-fields.—There are three little tracts, grouped by Mr. Hughes, who has surveyed them, under this name, lying between long. 86° 37′ and 87° 5′ E., to the north of the Barakar river. They do not require special notice, as they are economically unimportant.

Raigarh and Hingir Coal-field.—This coal-field, for an account of which we are indebted to Mr. V. Ball,† is situated on the south-west frontier district of Bengal, between the Ebe and Mahanadi rivers, north-west of Sambalpur; it is estimated to have an area exceeding 5,000 square miles, and is largely concealed by a covering of the newer "Hingir Group" of rocks. Several seams of coal have been noticed of fair promise, especially one at Dibdorah, which is 6½ feet in thickness and easily accessible. According to analyses of six seams given by Mr. Ball, the proportion of ash varies from 13 to 37 per cent., while the quantity of volatile matter is large. Iron ore is also present

* Mr. T. W. Hughes.—"Mem. Geol. Surv., India," vol. vii, Part II.

† "Records, Geol. Surv. Ind.," No. 4 (1875 with map).

in considerable amount in two or three zones in "the Barakar Group."

Nerbudda Coal-field.—This coal-field includes a considerable tract in Western India, lying in part along the valley of the Nerbudda River, and containing both coal and iron-ores. The district has been explored by several observers, the latest of whom, Mr. Medlicott, has drawn up a Report on behalf of the Geological Survey.* The actual extent of country over which these mineral deposits may be supposed to range has not been precisely determined, owing to the want of actual mining operations; but coal-seams of good quality and thickness have been observed along the banks of the Sitariva, the Tawa near Salyia, the Mahanuddi and Johilla Rivers; and Mr. Medlicott states that unquestionably from some of these localities large supplies of good coal might be obtained. The strata in which the coals occur belong to the Damuda series.†

The Bisrampur Coal-field lies in the eastern portion of Central Sirguja. It occupies an area of about 400 square miles, and is drained by the Mahan River and its tributaries, along whose banks sections of the strata with coal-seams are sometimes found. Owing, however, to thick deposit of diluvial matter which covers the district, its mineral resources are but little known, though Mr. Ball considers that good coal is unquestionably present.‡

* "Mem. Geol. Surv., India," vol. ii.

† At a meeting of the shareholders of the Nerbudda Coal and Iron Company, it was decided to sell the mines and works of the Great Indian Peninsular Railway Company for £40,000. The company has been in existence for 44 years. "Colliery Guardian," September 16, 1904.

‡ "Records of the Geol. Surv. of Ind.," No. 2, 1873.

GODAVERI VALLEY.

*Fandar Coal-field, etc.**—This field is situated near the village of Chimur, 30 miles N.E. of Warora, in the Chanda District. The existence of coal-measures under a small tract of Kamthi beds, 5 to 6 miles square, has been proved by boring. Three seams of coal have been ascertained to exist, and these have a maximum total thickness of 38 feet. The coal is similar in character to that of Warora.

Wardah or Chanda Coal-field, etc.†—This coal-field constitutes the northermost extremity of an immense tract of Gondwana rocks, which extend for about 285 miles from N.W. to S.E., in the valleys of the Wardah Pranhita and Godaveri basins. In Chanda there are deposits of rich iron-ore.

The group of rocks exposed is as follows :—

Upper Gondwana.

	Feet.
Kota Maleri	1,500
Kamthi	...2,500 to 3,000
Barakar	250
Talchir	250

Any attempt to give an idea of the distribution of coal-measures throughout this area, without employing a mass of detail, would certainly fail. I shall therefore confine myself to quoting Mr. Hughes' estimate of the amounts of coal in several of the particular tracts where its existence has been proved by actual outcrops or by borings.

* Hughes, "Mem. Geol. Surv. of Ind.," vol. xiii, pp. 145–154. "Manual," vol. i, p. 226.

† Hughes, *loc. cit.*, p. 145. "Report Coal-Commission," vol. iii, p. 237.

	Actual Quantity. Tons.	Amount Available. Tons.
Warora Basin	20,000,000	14,000,000
Ghugus	90,000,000	45,000,000
Wun	2,100,000,000	1,500,000,000
Between Wun and Papur ...	105,000,000	50,000,000
,, Junara and Chicholi ...	150,000,000	75,000,000
Sasti and Paoni basins	60,000,000	30,000,000
Total	2,525,000,000	1,714,000,000

The following assays will serve to convey some idea of the quality of the coals :—

	Warora.	Pisgaon.	Ghugus.*
Fixed carbon	45·4	65·1	45·61
Volatile matter ...	26·5	19·2	33·49
Water	13·9		
Ash	14·2	13·7	20·90

In Mr. Hughes' "Memoir" assays of samples from other localities are also given.

The Warora coal is deficient in fixed carbon, a larger percentage of which is essential where great heating power is required. It is also deficient in combustible volatile gases. Pisgaon coal, however, contains a more considerable proportion of fixed carbon, viz., 65·1 per cent.

The great outlay by the Government in connection with the exploration and testing of the field has not yet been nearly repaid, the cost of extraction being heavy.†

A special branch line conveys the Wardah coal to the Nagpur branch of the great Indian Peninsular Railway, by means of which it is distributed both for use on this line, and for factories.

* Average of 16 assays.

† £600,000 is stated to have been already expended at Warora alone at the time Mr. Hughes' Report was printed.

Several other small areas of coal-bearing rocks occur further down the course of the Godaveri Valley at Dumagudium, Mudavaram, etc., to which much interest has attached, as it was hoped that they might yield a supply of coal for the Madras Presidency, but the prospect of their doing so does not appear to be a good one.

*Kamaram.**—This name has been given to two small fields situated near the village of Kamaram, which lies 40 miles, a little north of east, from Warangul in the Hyderabad territory.

The larger one is 6 miles long, by about 1 mile broad; it consists of Talchir, Barakar, and Kamthi strata. It includes two coal seams of fair quality, measuring respectively 9 feet and 6 feet. The available coal is estimated at 1,132,560 tons, and it is stated to be equal to the average coal of the Wardah fields. Its position is unfavourable to its development, water carriage being too far distant.

The smaller field, which is about half a square mile in area, is of no importance.

Singareni Coal-field.†—This field is situated near the village of Singareni in the Hyderabad territory, about 30 miles to the S.E. of the Kamaram field. Its area is 19 square miles, the coal-measures being found throughout about 8 square miles. One coal seam was discovered, but being much concealed, its thickness was not ascertained; an assay of a sample from it gave:—

* King, "Records, Geological Survey of India," vol. v, p. 50. "Manual," vol. i, p. 240.

† King, *tom. cit.*, p. 65. "Manual," vol. i, p. 241.

Fixed carbon	62·4
Volatile	22·6
Ash	15·0
	100·0

Additional seams, one of them 21 feet thick, have since been proved by boring.

This field may possibly become of some economic importance, as there is a prospect of a railway being constructed at no great distance from it.

SIKKIM.

*Darjiling District.**—This field occupies a narrow zone, which stretches along the foot of the Himalayas, from Pankabari to Dalingkote. The rocks are Barakar beds probably, which have been much crushed and tilted, dipping at angles of from 40° to 90° to N.N.E., or towards the main mass of the hills. Frequently the sandstones have been converted into quartzites, and the shales into splintery slates. Much of the coal is in the condition of powder, and some of it has assumed the character of graphite. The effect of the compression has been to reduce it by removal of the volatile portions to the condition of an anthracite. Some experiments were made with a view to utilizing it in the manufacture of artificial fuel, but the process found to be requisite was too expensive, and the difficulty of boring in these crushed rocks is so great as to render it improbable that this coal will ever be commercially available.

One seam is 11 feet in thickness. The average of five assays of the coal gives the following composition :—

* "Mallet, "Memoirs, Geological Survey of India," vol. xi. "Manual," vol. i.

Carbon	70·66
Volatile	9·20
Ash	20·14
	100·00

Into a description of the complicated geological relations of these beds with those forming the adjoining mass of the Himalayas, I do not now propose to enter. Mr. Mallet has arrived at the somewhat startling conclusion that the coal-measures are younger, and underlie the highly metamorphosed rocks of the outer slopes. To do justice to his arguments would require more space than is at present available for the purpose.

The fact that this locality is the only one north of the Ganges where Gondwana rocks occur, is of great interest in connection with any discussion as to the early relations which existed between the Peninsular and Himalayan regions, and indeed the formation of the Himalayas themselves.

ASSAM.*

Five distinct coal-fields exist in the valley of the Bhramaputra, in the province of Assam. They are distinguished by the following names:—33, Makum; 34, Jaipur; 35, Nagira; 36, Janji; 37, Disai.†

It will be convenient in this abbreviated account to treat of them collectively.

* Mallet, "Memoirs, Geological Survey of India," vol. xii, Part. II. "Manual," vol. ii, p. 701.

† The numbers refer to those given by Mallet. See George Turner in "Coal-mining in Assam." "Trans. Fed. Inst. Mining Engineers," vol. 10, Part II, p. 356 (1896).

Some uncertainty exists as to the age of the rocks, but the balance of evidence seems to favour the view, that it is middle Tertiary (Miocene), and therefore distinct from the Cretaceous and Nummulitic coal-formation of the Khasi hills.

The coal differs from that of the Indian coal-fields in having a homogeneous structure, and in the absence of lamination; the average of the assay of twenty-three samples gave :—

Moisture	5·0
Carbon...	56·5
Volatile	34·6
Ash	3·9

This shows a high quality of fuel as compared with Indian coals.

The opening up of these fields is a point of the highest importance, since at present coal is carried 1,000 miles from Bengal for the navigation of the Bhramaputra; thus causing a ten-fold increase on the prime cost.

It is possible that some of the coal of the Khasi Hills above alluded to, may prove of value hereafter; but the same does not, so far as is known, seem probable in reference to the Tertiary coals of the North-West Provinces, although hopes in that direction have often been expressed; and a project for the exploration of one of these deposits has, I understand, recently assumed a tangible form, a company having been formed, the result of whose operations will be watched with interest.

Salt-Range, Punjab.—Beds of coal and lignite of inferior quality occur near Bhaganwala, Pid, and Samundri. They belong to the Jurassic and Tertiary periods, and are

described in detail by Mr. Wynne in his valuable memoir on the Salt-Range.*

* "On the Geology of the Salt Range, Punjab," "Mem. Geol. Survey, Ind.," vol. xiv. These deposits were previously reported upon by the late Dr. Oldham for the Indian Government. The report is not encouraging.

CHAPTER III.

The following is the output of coal in India for 1902 and 1903,* for which I am indebted to Prof. Dunstan, F.R.S.:—

—	1902.	1903.
	Tons.	Tons.
Assam	221,096	239,328
Baluchistan	33,889	46,909
Bengal	6,259,236	6,361,212
Burma	13,302	9,306
Central India	171,538	193,277
Central Provinces...	196,981	159,154
Hyderabad (Deccan)	455,424	362,733
Punjab	55,373	43,704
Kashmir (prospecting)	1,138	999
Rajputana (Bikaner)	16,503	21,764
Total	7,424,480	7,438,386

Summary.—From the above brief description of a few of the coal-fields of British India, taken from the careful and elaborate reports of the Government Surveyors, which are accessible to all, it may be gathered that Northern India has all the materials for the development of com-

* In Bengal there were 218 collieries at work in 1895; in 1896 the number of collieries was reduced to 154, though the quantity of coal raised was greater. An excellent map of the Jherriah Coal-field, by Mr. G. E. Stonier, late Chief Inspector of Mines in India, is published by the "Colliery Guardian," September 16, 1904. The Jherriah Coalfield is traversed by the Damuda River, in Bengal.

mercial and industrial pursuits. The valley of the Ganges, navigable for such great distances inland from the ocean, and now traversed by lines of railway, has also enormous stores of coal and iron—those materials which have been the source of the wealth of Great Britain itself. It is also a cotton-growing country, and there is therefore no apparent reason why cotton might not to a larger extent be manufactured where it is grown. With such advantages, Northern India *may* become a great manufacturing country. Whether it *will* become so is a question which will be determined on moral and social grounds; depending on the enterprise, perseverance, and intelligence of the people themselves.

CHAPTER IV.

COAL-FIELDS OF CHINA, MANCHURIA, MALAYSIA, JAPAN, AND BORNEO.

China.—The laborious researches of Baron von Richthofen, the enterprising traveller, together with the accounts received from time to time through other sources, leave no doubt that there are large deposits of coal in this great empire. The provinces of Hoonan and Shansi, lying to the south of the Yang-tse-Kiang, are richly stored both with coal and iron. In the latter province the Baron came upon a region which he describes as "one of the most remarkable coal and iron districts in the world."* He considers it to be in extent considerably greater than that of Pennsylvania. These vast resources are not utilized by the natives, owing to unskilfulness in mining, and chiefly to the absence of roads. Another of these districts lies near the city of E-u, in the prefecture of King Hua (lat. 29° 15′ N., long. 119° 46′ E.). The coal is here worked in pits from 300 to 500 feet in depth, and the mines are opened out into galleries branching off into the seams at successive stages in the descent.† The mineral is also worked in the cliffs of the Pe-Kiang River at

* From report forwarded to the Foreign Office, and quoted by Sir R. Murchison in the Anniversary Address to the Roy. Geog. Soc., London, 1871.

† Rev. R. H. Cobbold, "Journ. Geol. Soc.," vol. xii.

Tingtih, by means of adits driven into the side of the hill at the outcrop of the coal-seams ; and lastly, at a place 5 miles from the city of Whang-shih-Kang on the River Yang-tse-Kiang, an account of which is recorded by Mr. Oliphant.* Extensive coal-deposits occur in Central Manturia, near Mukden, worked by a branch from the railway to Port Arthur.

The working of coal in China dates probably from a very ancient period. Our earliest notice is by the celebrated traveller, Marco Polo, towards the close of the thirteenth centuary.

As regards the geological age of the coal-formations of China, the evidence which we possess leads to the conclusion that they are more recent than the Carboniferous, and probably of Mesozoic age. Remains of cycads are abundant, and have been collected by Mr. R. Pumpelly ;† on the other hand, the characteristic Carboniferous genera and species are apparently wanting. It seems, therefore, not improbable that the newer Indian and Chinese Carbonaceous deposits are of the same, or nearly the same, geological age.

Malaysia and Japan.—That magnificent group of islands lying between the Indian and North Pacific Oceans, seems to be as rich in the mineral treasures of the past as it is in the vegetable productions of the present. Besides gems, and metallic ores in abundance, including iron, which yields the unrivalled Japanese steel, several of these islands contain strata stored with coal. And when we regard the geographical position of these islands, lying on the confines of the Eastern hemisphere, and in the track of

* "Lord Elgin's Mission to China and Japan," vol. ii, p. 389.

† "American Journal of Science," September, 1866.

vessels trading between America and Asia, the economic value of these sources of fuel can scarcely be over-estimated. It was on this account that the American expedition to Japan kept steadily in view the establishment of depôts for coal on several points on the coast of those islands, for the supply of American steam-vessels * With a similar object, the Indian Government have given attention to the supplies of coal known to exist in Borneo, and have been successful in inducing the chiefs to form depôts of coal on the coasts. It is also satisfactory to learn that the trials made both in New York, Calcutta, and in the steam-vessels themselves, of samples of coal from these islands, are very favourably reported.

In Japan, coal-mines are worked in the districts of Kiusin and Niphon; and the testimony of Kæmpfer regarding its abundance is corroborated by that of the officers of the American expedition. The Islands of Formosa and Karapty, the latter of which is now appended to the Russian Empire, also contain this mineral in considerable quantity.†

The Hokkaido Colliery and Railway Company.‡—The Hokkaido Colliery and Railway Company (the Tanko Tetsudo Kwaisha) was organised in 1889, to operate coal-mines and railways in Hokkaido, Japan. One of the first acts of the new company was to buy from the Government

* "American Expedition to Japan." The Geological Map of the Japanese Empire, Scale 1 : 1,000,000, issued by the Imperial Geological Survey of Japan, does not indicate the existence of a coal-formation, but the presence of coal itself is shown by a small cross (×), which, amongst the numerous details, is not always clearly visible.

† Atkinson's "Travels in the Amoor."

‡ "From a paper by K. Yonekra, manager, written for "Mines and Minerals." "Colliery Guardian," September 16, 1904.

the Poronai Railway and the Poronai Coal-mine. Afterwards the Ikushunbetsu Coal-mine was purchased, and new mines were opened in Sorachi and Yubari. A line of railway was built from the Port of Muroran to Sorachibuto, with branches to the Sorachi and Yubari Mines. The Government granted a subsidy of 5 per cent. on the money expended in building railways up to the end of 1899. The capital of the company was originally 6,500,000 yen, but has been gradually increased to 18,000,000 yen (1 yen equals, practically, 50 cents). Since 1894 the company has declared dividends of from 12 to 15 per cent. each year.

The railways owned and operated by the company are 212 miles in length. One railway starts from the Port of Otaru, on the N.W. coast, and the other from Muroran on the S.E. coast. They meet at Iwamizawa and run northward to Sorachibuto, where the line connects with the Government railway. There are branches to the four collieries now worked by the company, and the coal is transported direct to the Ports of Otaru and Muroran. The company, besides furnishing coal to the prominent steamship companies and manufacturing plants, ships coal to Shanghai, Hong-Kong, Manilla and even to Singapore, distant over 2,000 miles. The main office of the company is in Sapporo, Hokkaido. The head office of the mining department is at Yubari Mine, and that of the railway department is at Iwamizawa Junction. Besides, there are many branch offices, where stores of coal are kept, one of the chief ones being in Tokio, where much of the selling is done. The total output of the coal from the four mines during the years 1899—1902, inclusive, is as follows :—

	Tons.
1899	547,336
1900	601,159
1901	751,844
1902	885,704

In Borneo, the province of Labuan on the N.W. coast abounds in coal, and there is at least one important colliery now in work.* Several beds crop out near the River Gooty, at the N.E. of the island. Mr. Bellot states that the mineral resembles the best cannel, and burns readily.† It also occurs in Pulo Cheremin, an island at the mouth of the Borneo River.

Mr. J. G. H. Godfrey has described a coal-bearing series of strata at Horimui of considerable extent, best developed in the western part of Japan, and considered on fossil evidence to be of Cretaceous age.‡

* At this colliery there are four seams.

	Ft.	In.
No. 1 seam	4	6
,, 2 ,, ...	2	9
,, 3 ,, ...	3	9
,, 4 ,, ...	11	3
Total	22	3

A new colliery is being put down, intended to raise 100,000 tons per annum; as I am informed by Mr. R. M. Smith of Edinburgh (1873).

† Mr. T. Bellot, "Journ. Geol. Soc.," vol. iv.

‡ "Notes on the Geology of Japan." "Proc. Geol. Soc., Lond." (1877-8).

CHAPTER V.

AUSTRALIA.

THE great Anglo-Saxon Empire, which is springing up at the antipodes, seems to have all those mineral resources so necessary to the commercial prosperity of a nation. Amongst these, coal is not the least important; and that it occurs in vast quantities will be apparent from the following brief statements of each of the provinces into which Australia has been parcelled.

Victoria.—The state of Victoria contains Carbonaceous deposits, from which coal has already been extracted. The late Government geologist, Mr. Selwyn, was engaged for several years in investigating the mineral resources of this highly-favoured colony, and has prepared very fine maps of the coal districts. Mr. Selwyn states that if the mass of the coal-bearing strata of Victoria be Oolitic (Jurassic), there are certainly others in the eastern districts of the colony which contain plants of the true *Carboniferous* type, while the beds themselves rest and pass downwards into calcareous rocks with fossils which are nearly all Carboniferous or Devonian forms.* How remarkable, that both here and at our antipodes, in Britain in the Northern and Australia in the Southern hemisphere—countries now standing in the relation of parent and child—Nature should

* "Geology of Victoria," "Journ. Geol. Soc. London," vol. xvi, p. 145.

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have been elaborating mineral fuel during the same eventful period of the Earth's bygone history!

*New South Wales.**—This coal-field extends along the coast of the Pacific Ocean from Sussex Haven to Port Stephens, a distance of 200 miles, and inland to the base of the Cordilleras, having an area of over 15,400 square miles, and contains numerous seams of bituminous, steam, and gas coal, besides beds of "Kerosine," or oil-shale, and of iron-ore. The beds belong to the Carboniferous series, as shown by the late Rev. W. B. Clarke, and are largely charged in their lower part both with fossil shells and plants similar to those of the Carboniferous series of Western Europe and Britain.

The general succession of the strata, according to Messrs. Clarke and Wilkinson, is as follows:—

	Feet.
(*e*) Wianamatta Series, shales with fish, *Palæoniscus*, fresh water shells and plants	500
(*d*) Hawkesbury Series, chiefly sandstones with ferns (*Cyclopteris Browniana*)	1,000
(*c*) Upper Coal-measures of Newcastle with plants, etc. (*Glossopteris*, *Sphenopteris*, *Conifers*); 16 coal-seams over 3 feet in thickness	480
(*b*) Upper Marine Beds, shales, sandstones, and coal, numerous shells, *Productus*, *Spirifera*, Crinoids	350
Lower Coal-measures, shales, sandstones, with similar fossils	100
(*a*) "Lepidodendron Beds," shales, sandstones, etc., with plants, *Knorria*, *Sigillaria*, *Lepidodendron*, resting unconformably on the Devonian Rocks.	

The Wianamatta series is said to rest unconformably on the Hawkesbury series, and is probably of a later geological

* "Mines and Mineral Statistics of New South Wales" (Sydney, 1875), containing reports by Mr. C. S. Wilkinson, Government Geologist, the late Rev. W. B. Clarke, Prof. Liversidge, Mr. Mackenzie, Examiner of Coal-fields, and others.

age; the lower groups (*a* and *b*) clearly indicate an age corresponding to that of the Carboniferous rocks of Great Britain.*

In 1874, 1,304,567 tons of coal were raised, and a good deal exported from Newcastle. The output is yearly increasing, and in 1903 reached 3,278,000 tons.

No one has contributed so largely to our knowledge of the coal resources of New South Wales as that indefatigable explorer, the late Rev. W. B. Clarke. Some years since I was favoured by him with a general summary of the results arrived at up to 1861 (since extended), which are of increasing importance to the development of the colonies, as also to the progress of communication by railways, which have sprung into existence since the Exhibition of 1855, and to steam navigation, now rapidly advancing, as well as to manufacturing establishments rising around. The following are extracts from Mr. Clarke's summary :—†

"In the year 1847, the author of this notice stated (in evidence before a Committee of the Legislative Council) that he had then obtained acquaintance with the existence of Carboniferous formations over from 17,000 to 18,000 square miles on the eastern side of the Colony, between 32 degrees and 35 degrees south. Since then, his own experience

* Prof. McCoy considered the upper plant-bearing beds to be of Jurassic age, and to be stratigraphically disconnected with those bearing coal. Prof. J. Morris seems to have held a similar view. On the other hand, the late Prof. Jukes, writing in 1850, three years after the publication of Prof. McCoy's valuable papers, expressed his opinion that the whole series was "one great continuous formation." Dr. Oldham, in reviewing the relations of the Coal-formations of New South Wales and of India (Damuda group), came to the conclusion that they are identical in age, *i.e.*, at the confines of the Palæozoic and Mesozoic epochs. "Mem. Geol. Survey of India," vol. ii, p. 333.

† Dated, "St. Leonard's," October 19th, 1861.

has been much enlarged during his explorations of Australia; and, coupling his present actual knowledge with the information derived from other explorers, he is now enabled to state that, compared with its gold-fields, the Carboniferous portion of this territory is of infinitely greater importance than was at that time supposed."

On the east coast of New South Wales, the Carboniferous formation presents itself with little interruption, except from extensive dykes of trap (of which the basaltic dykes strike N.E., and the greenstone dykes, which are well exemplified on the coast at Newcastle, strike N.W.), from between 31 deg. 30 min. south, to at least 36 deg. south; and in two principal parts of this coast line, valuable coal-seams occupy the cliffs washed by the ocean, about Newcastle and the north of Illawarra. The position of the former is very advantageous for all the purposes of commerce; the latter has some disadvantages, owing to the difficulty of approach to the cliffs from seaward.

As in Newcastle-upon-Tyne, so also at Australian Newcastle, vessels can receive coal immediately from the mines at the mouth of the Hunter River, which, by structures erected on a grand scale, has been turned into an accessible and safe harbour. The coal-fields lie close by the sea-shore, some beds cropping out even upon the steep coast-bluffs, so that they can be distinctly seen from the sea, on a voyage from Sydney to Newcastle. There are, also, in the vicinity of this town, already 11 known seams extending over an area of about 6 miles along the coast, and 20 miles into the interior, having a thickness of from 3 to 30 feet.* The analysis of this coal gives: carbon 74·13 to 78·0, hydrogen and oxygen 25·87, ash 5·0, water 1·6.†

* Hochstetter's "New Zealand," "Eng. Trans.," p. 75. † *Ibid.*, p. 91.

At Ballambi Point, north of Wollongong, operations for the shipment of coal, brought by a tramway from the seams situated in the Illawarra escarpment, have been some time carried on. Steps are also in progress for the commencement of a breakwater harbour at that point, where the mineral treasures of vast extent, from no less than 12 seams, will be available for transport; and at Wollongong a new basin is being excavated.

"As some of these seams are traceable for many miles both northward and southward, the Illawarra will ere long supply abundance of fuel well calculated for the purposes of navigation.

"Passing to the coast north of the Hawkesbury, we find another series of seams extending from the Tuggerah Beach Lake to the left bank of the Hunter; the cliffs about Newcastle presenting an escarpment varying up to 300 feet, in which seams of coal, that are worked inland, present themselves. Other seams occur in the Western Flats, and have been worked to various depths down to 400 feet below the sea. Within the last few years numerous fresh openings have been made, and some rich seams, fully equal in thickness to the Nine-Feet Upper Illawarra Seam, have been discovered.

"Passing to the westward, the whole valleys of the Hunter and the Goulburn offer occasional occurrences of valuable Carboniferous deposits; as at Stony Creek, near Maitland, at Anvil Creek, and other localities, five seams occur at an enormous depth below the Newcastle Beds. The following localities indicate some of the places where coal has long been known, viz.:—Four-Mile Creek, Hexham, base of the Myall Range, Wollombi, Morpeth, Maitland, Wallis Creek, Anvil Creek, Purrendurra, Glendon

Brook, Tolga Creek on the Paterson, Leamington, Wollon, Jerry's Plains, Sadleir's Creek, Foy Brook, Falbrook, Ravensworth, Maid-Water Creek, Muswell Creek, Edenglassie, Piercefield, north of Bengala, at Gill's Cliff and Coyeo on the Page, near Murrurundi and Harbenvale, Kingdon Ponds, Mount Wingan, near Scone, and at the junction of the Hunter and Goulburn, as well as higher up on the latter river, near Gummum. Coal-beds also occur on the Talbragar and Cudgegong Rivers.

"South-east of these localities, coal appears at the foot of Mount York, and at Bowenfells, near Hassan's Walls; on the Rivers Coxe and Wollondilly, on the Nattai, at Barragorang, on Black Bob's Creek, to the west of the Southern Hanging Rock, at Balangola Creek, west of Arthursleigh, in the deep gullies about Bundanoon, Meryla, and the Kangaroo Ground. Below the plateaux, on which the seams crop out on the face of the Illawarra escarpment, above Jamberoo and Mullet Creek, and below Mounts Kembla and Keera, seams, to the number of 12, occupy patches of cliff along the coast from near Waniora Point to a great fault 10 or 12 miles northward; northwards of which, at Gara, the beds of shale connected with the coal rise at an angle of from 2 to 4 degrees from beneath the Hawkesbury Rocks, which thence to the north of Brisbane Water occupy the coast. This dip seems general in the Illawarra, and also occurs on the Hunter; but it varies up to 16 degrees on that river, and north of the Karuah to 50 degrees, and in places to 90 degrees.

"Passing on thus to the country about Port Stephens, between the Karuah and the Manning, we find a region of coal full 25 miles in extent, in which are no less than 18 seams; of which one, measured by the writer, was 30 feet thick.

"This region has since been surveyed by M. Odernheimer of Nassau, for the Australian Agricultural Company, in whose estate this field occurs.

"Coal occurs in patches in other parts of New South Wales, and has been occasionally worked to the north of the Mittagong Range in the steep face of cliffs above the Nattai Creeks, near the Fitzroy Iron Works.

"Respecting the position of the coal in some of the localities, it may be observed, that the strike and joints of the rocks lead to the conclusion that the coast line merely intersects obliquely the general area or basin, which has thus its minor axis along the Hawkesbury; the Newcastle Seams finding their prolongation about the Werriberri Creek on the Warragamba River, and the Bullai Seams having had their northern prolongation many miles in advance of Newcastle, in a tract destroyed by, or below, the sea; all the evidence collected by observation leading to the inference that this eastern coal-field is only a portion of a once much larger area, distinctive portions of which are occasionally thrown up by the sea on the beach rocks and sands. This is true, especially, of the Illawarra, where at Towrudgi Point, north of Wollongong, fossil wood and trees exist near low-water mark, imbedded in natural position in the rocks; and at Ballambi, where similar trees are entangled, two seams of coal making their appearance also just behind the beach, and at and below the sea-level; and after gales, the beach at Wollongong is strewn with fragments of these and other Carboniferous spoils. Similar fossilised wood occurs at Newcastle, and in the Palæozoic Beds of Black Head, south of Kiama, and of Stony Creek near Maitland.

"Judging from the enormous development of the

Hawkesbury Rocks on the western slopes of the Cordillera, where they occur in patches at very great elevations on the summits of the older formations, or on the plains from the western end of the Liverpool Range to the parallel of 26 degrees south, it may be fairly concluded that there is no present possibility of calculating the actual amount of available coal on that side of the colony. Seams of coal are known, however, to occur in this area, on the Castlereagh ; near the Nudawar Ranges, and on Reedy Creek, near Warialda, whence the writer procured Cannel Coal.

" A considerable portion of the counties of Clarence, Richmond, and Rous is occupied by a similar formation, and workable coal exists therein both on the Richmond and Clarence Rivers."

Queensland.—" The districts of Darling Downs and Moreton Bay are now constituted parts of the new Colony of Queensland, and coal-seams exist on the Bremer and Brisbane Rivers, and along the shores of the Bay, as on the coast, and on Mount Keera. Here the coal-seams are accessible by adits, and on the Brisbane the steamers can load by lying literally at the mouth of the mines, as is the case at Lake Macquarie. This phenomenon is characteristic of the coal of New South Wales. It is due to three principal conditions:—1. The generally nearly horizontal planes of some of the seams ; 2. The elevation of the coal-country above the sea-level ; and, 3. The persistent nature of the joints which traverse these elevated beds, at right angles to the planes of bedding, thus occasioning continual escarpments, in which the out-cropping seams appear on the faces of cliffs, or in more or less accessible ravines.

" To the northward of the Condamine, the Carboni-

ferous formation extends over vast regions in which coal undoubtedly exists. The writer has reported (Report X, Oct., 1853) the formation on the Condamine as occupying probably 20,000 square miles. He calculates also, from such data as are available, that on the M'Kenzie it occupies an extent of 40,000 square miles; and on the Robinson, 20,000 square miles. The country between the Condamine and the parallel of 32 degrees, occupied by similar beds, cannot be less than 15,000 square miles. And if we take into account the facts stated by Sir T. L. Mitchell, in his history of the explorations of the far interior, and the existence of the same Carboniferous formations, not only in various parts of the littoral districts of Victoria, but as far as the Grampian Mountains, westward of the 143rd meridian, it becomes manifest that there is no country on the globe, America excepted, occupied to so large an extent by these formations as Australia; and, with trifling exceptions, nearly all the enormous areas occupied by these Carboniferous beds belong to New South Wales and Queensland."

Tasmania.—"This district abounds, also, in coal-beds, some considered the equivalents in age and position of the Illawarra and Newcastle seams of New South Wales; others, the equivalents of the *lower* coal-seams of Stony Creek, near Maitland, occurring in the midst of a Palæozoic Fauna. The author's opinion of these Tasmanian coal-fields, as formed from personal inspection, has been confirmed by Mr. Gould, the Geological Surveyor of that Island, in his recent Reports to the Tasmanian Government.

"That gentleman has also discovered evidence to prove that the 'combustible schists' or 'Dysodile' of the

Mersey River, on the North Coast of Tasmania, contain zoological fossils of Palæozoic age. In New South Wales, beds of a similar kind exist, of which specimens are exhibited from the higher northern slopes of the Liverpool Range, and from the base of Mount York in the County of Westmoreland. Examination shows that they are charged with *resin* (probably not unlike that so abundant in the New Zealand coal) ; and, therefore, they may perhaps be valuable as a source for the manufacture of mineral oil. The specific gravity of some of this substance the author has found to be 1·204. In appearance it is like lignite passing to cannel. It ignites readily, and burns with a prevailing odour. It is highly conchoidal in fracture, and lies in masses from 6 to 12 inches thick. A somewhat similar substance occurs in the Island of Cuba, and there is called *Chapapote ;* but the New South Wales mineral is not so bituminous, and the specific gravity is less."

There are workings at Tasman's Peninsula, Port Seymour, New Town, and the Don. The coal is both anthracite and bituminous.*

Coal-fields of New Zealand.

This wondrously rich and varied group of islands seems to abound in all the mineral products of Nature, not excepting coal. It is true that, for the present, gold almost absorbs the interest of its inhabitants, but this is only for a time ; and as the grains and nuggets of this precious metal are washed out of the alluvial gravels, and gradually diminish in abundance, so the beds of coal will assert

* "Hints to Emigrants to Tasmania," by Mr. H. M. Hull (1871).

their paramount importance as a source of prosperity and wealth to the inhabitants.

For a series of years, the Carbonaceous deposits of New Zealand have attracted the attention of naturalists who have visited this country.*

Mr. C. Forbes, surgeon on board H.M. Ship *Acheron*, sent a very interesting account of the coal-seams of a large extent of coast, and of the experiments made on their qualities and composition, which he published in the Journal of the Geological Society of London, vol xi, 1855.

In 1859, Dr. F. von Hochstetter, accompanied by his friend and travelling companion, Dr. J. von Haast, were appointed by the Government to commence explorations in the provinces of Auckland and Nelson; and this latter geologist, after having finished, in 1860, some important observations in the western districts of Nelson, was appointed Geologist by the Provincial Government of Canterbury. The labours of these enterprising naturalists have thrown much light on the coal-resources of large portions of the Island. Finally, in 1861, Sir James Hector was appointed Geologist to Otago, and he has since (in 1866) published an able Report on the coal-deposits of the country, in which he divides the Carbonaceous deposits into two classes, the hydrous and anhydrous; the former being similar to the brown-coals of Europe, the latter being referable to the Mesozoic epoch, and more closely resembling "stone-coal."

The results of Dr. Hochstetter's explorations, and those

* One of the first observers on the geology and palæontology of the island was Mr. Walter Mantell, son of the late Dr. Mantell, author of the "Medals of Creation," who sent home through his father communications on the geology of parts of the country to the Geol. Soc., London, 1848.

of his companion during their joint survey, are given to the world in a noble work in which the physical history and structure of the Islands are graphically portrayed together with their natural history.*

Character and Geological Age of the Coal deposits.—The coal-seams of New Zealand are distributed over portions of both the North and South Islands ; they occur in the form of *lignite*, a mineral fuel of inferior quality, and also of *brown-coal*, sometimes in thick beds, and of a quality not inferior to that of the best kinds of the German brown-coal, which is only inferior to English Carboniferous coal. This latter is considered to be of Mesozoic age, probably Jurassic. It is uncertain whether there is any "stone-coal" of Palæozoic age in this country.

North Island.—Deposits of brown-coal occur in the Drury and Hunna districts, 20 miles south of the city of Auckland. The vicinity of the capital, and of the Waitemata and Manukau Harbours, with which communication has been established (1862), renders this coal-field very important. The merit of its discovery, in 1858, belongs to the Rev. Mr. Purchas. There is, *at least*, one bed of brown-coal, 6 feet in thickness, associated with remains of dicotyledonous plants, which leads Dr. Hochstetter to infer its Tertiary age.

Another tract with brown-coal lies on the banks of the Waikato, but is at present unopened ; one seam here has a thickness of 15 feet, and lies in a horizontal position along the base of the slate mountain Taupiri.

A coal-formation of probably Mesozoic age has recently been detected in the northern districts of Auckland, in the

* "New Zealand, its Physical Geography," etc. (1863), Stuttgart, translated by E. Sauter (1867).

vicinity of Wangaroa Harbour. A large portion of the isolated hills at the North Cape is composed of this formation. According to Dr. Hector, the bituminous coal of Kawa-Kawa is of a quality superior to that of any other coals of the province.

Besides the above, there are to be found on the shores of Manukau Harbour, in the flats of Drury, Papakura, and Waikato, etc., deposits of *lignite*, which must not be mistaken for brown-coal.

South Island.—Of greater variety and extent appear to be the coal-deposits of South Island, which seem destined to be capable of supplying a large portion of the fuel for the steam navigation of the Pacific Ocean. At a distance of 4 miles south of the city of Nelson, a colliery has been opened in several seams of *brown-coal*, from 3 to 6 feet in thickness. Still farther south near Mount Arthur, and on the Wangapeka and Batten rivers, coal-seams have also been discovered.

The coal of Massacre, or Coal Bay, west of Nelson, has been opened to a small extent. The seams lie at the level of high-water mark and below it, in a nearly horizontal position; and the coal has been used for steam navigation purposes.*

The extent of the coal-field near Motupipi is considerable; the coal-seams having been found at various places up the Takaka River for a considerable distance. They belong to the *brown-coal* series, and are imbedded in bituminous shales, sandstones, conglomerates, and limestones, such as are frequently met with in Germany.†

The coal-deposits of Pakawau, in Golden Bay, appear

* On board the *Nelson* in 1854–5.

† Hochstetter, "New Zealand," p. 84.

to be of a different, and more ancient, date than those just described. The coal is of a firmer consistency and gaseous, but has not yet been found of sufficient thickness to induce extensive mining operations. The extent and resources of this coal-field are as yet little known.

Dr. Haast has made important discoveries of coal in the provinces of Nelson and Canterbury; especially on the Buller (or Kawatiri), and Grey (or Mawhera) Rivers.* On the flanks of the Papahaua Range, he discovered a fine bed of coal 8 feet thick at a height of 1,500 feet above the sea, and extending over an estimated area of 8 miles in width by 15 in length.

Of still greater importance are the discoveries on the Grey River entering the sea on the west coast. Here two workable seams are known in the Waipara (Cretaceo-Tertiary) formation, of which the lower is 16 feet; they are interbedded with micaceous sandstones and shales, which have yielded dicotyledonous leaves, and remains of Cycads, with *Zamites*, *Pecopteris*, and *Equisetum*. The coal resembles that of Newcastle in Australia, and is little inferior to English coal.†

The coal-deposits of Pakawau, the Buller, and Grey Rivers are considered by Dr. Hochstetter to be of Mesozoic

* An analysis of the coal from Nelson at the mouth of the Grey River, by Dr. Percy, gives the following results:—Carbon 79·00, hydrogen 5·35, oxygen 7·71, ash 3·50, water 1·05, and coke 64·32 per cent. It is a caking coal, and probably a good gas coal. ("Metallurgy," p. 100.)

† See Dr. Hector's "Report" (1866). The grey coal is described as compact, black, of a dull lustre, with slaty cleavage. The coal puffs up slightly when heated, and gives 68·37 per cent. of coke. A concise account of the coal-seams of the Provinces of Canterbury and Westland will be found in the work of Dr. von Haast in the geology of those provinces, p. 450 (Christchurch, 1879).

age, and probably the representatives in time of the Yorkshire Oolitic coal in England.

The analysis of the Pakawau coal gives the following results—carbon 66·72, hydrogen and oxygen 23·18, ash 8·4, water 1·7.*

On the eastern side of the South Island, Carbonaceous deposits have also for some years past been known to occur. The Kowhai coal-field, about 30 miles from Christchurch in Canterbury, contains several workable seams, in which a coal-mine has been at work since 1857. Deposits of brown-coal are also known to underlie the great Canterbury plains, and crop out in the valleys of the Selwyn and several other rivers, and in the Malvern, Big Ben, and Somers Hills.

The province of Otago also contains deposits of *brown-coal* on the southern coast, north from the Molyneux River, where they extend over an area of at least 45 square miles, and in which there are several seams of good coal varying from 6 to 20 feet in thickness. Two large mines have been opened in this field, and the coal is used chiefly for the purposes of steam navigation. The same formation occurs in the Green Island and Saddle Hill Basin, where two seams of a thickness of 7 and 9 feet have been worked.

A third tract of the brown-coal formation occurs along the eastern sea-board of Otago, extending inland to the base of the Kakanui Mountains; and other small patches occur at intervals in the interior portions of the province. The same formation is also known to occur in South Island in several places.

* Herr *v.* Hauer, quoted in Hochstetter's "New Zealand," p. 91.

In 1903 the output of coal in New Zealand amounted to 1,420,193 tons, consisting of the following varieties:—

	Tons.
Anthracite, steam, and bituminous	879,891
Pitch	21,116
Brown coal...	441,814
Lignite	77,372
Total	1,420,193

being an increase of 57,491 tons on the previous year.*

With resources in mineral fuel so great, together with those supplies of the useful or precious metals which she is known to possess, New Zealand seems to have all the materials for the foundation of commercial and manufacturing prosperity. And when added to this we take into account the extraordinary fertility of her soil, and the sub-tropical character of her climate, her ample supplies of water, ever flowing down from groups of hills in the interior, or ranges of snow-clad mountains, appropriately called "The Southern Alps," and recollect that all these have been entrusted to the authority of a British Colonial Government, bringing with them the institutions, the traditions, and the enterprising spirit of the mother country, may we not predict for the "Britain of the South" a great and glorious future?

* "New Zealand Official Year Book," 1904, p. 334.

CHAPTER VI.

AFRICA.

As compared with the other continents Northern and Central Africa, as far as it is at present known, appears to be remarkably destitute of fossil fuel; nevertheless, the researches of Livingstone have brought to light coal-deposits on the banks of the Zambesi, described by the late Mr. Thornton, geologist to the exploratory expedition. Dr. Livingstone has rightly estimated the beneficial effect upon the future navigation of this great river, likely to be exerted by the existence of these "stones that burn," the term by which the natives designate this mineral.*

In South Africa considerable tracts of coal and iron-bearing strata have recently been explored, both in the Cape Colony, Natal, the Orange River State, and in the Transvaal. Mr. E. J. Dunn has drawn up a Report on the occurrence of two sets of coal-bearing beds on the N.E. margin of the Stormberg (near Bushman's Hoek), north of Queenstown—one of probably old "Carboniferous" age, and the other belonging to the upper part ("Stormberg") of the great Karoo Series—as indicated in the Quart. Journ. Geol Soc., vol. xxvii, p. 52; and, though the Report above noticed does not support that view, something like

* In Livingstone's second journey, coal was discovered at Tette, on the Zambesi, one seam being 25 feet in thickness.—"Expedition to the Zambesi and its Tributaries," p. 52, 1865.

it is now proved to be the case at about 150 miles west by south from Queenstown. Mr. Dunn has found an exposure (*inlier*) of some underlying coal-bearing (anthracitic) strata distinct from the surrounding and unconformable Karoo Beds, at Buffel's Kloof, on a spur of the Camdeboo Mountains, between Graaf-Reinet and Beaufort West; and again at Brandewyn's Gat, by the Leeuwe River, on a spur of the Nieuwveldt, 36 miles N.W. of Beaufort West, and 100 miles west of Buffel's Kloof. By making careful sections of the strata between Beaufort and Graaf-Reinet] and by examining the sections opened out by the new railway running S.W. from Beaufort across the Dwyka, Bloed, and Buffel's Rivers and the Wittenberg range, Mr. Dunn has fully explained the relation of the horizontal Karoo series as unconformable to the underlying tilted, folded, and broken "Ecca Beds," with their inclosed and conformable "Dwyka Conglomerate."

At Buffel's Kloof the diggings and shaft clearly show that one or more rather thick seams of coal (anthracite), in the underlying inclined beds have been broken and crushed by a fault, and even forced up into the higher fissures contained in the overlying horizontal Karoo beds, which do not hereabouts contain coal. The shales in which the coal is bedded contain "Glossopteris and Calamites!"*

Mr. Dunn describes the constituent strata of the Stormbergen as—at top—1. Volcanic: lavas, tuff, agglomerate, ash-beds, and amygdaloids, with volcanic bombs in sandstone, about 400 feet. 2. Cave-sandstone: buff-coloured, pinkish, greenish, white and grey, fine-grained, thick-

* "Report on the Camdeboo and Nieuwveldt Coal, Cape of Good Hope." (1879). See notice in "Geol. Mag.," November and December, 1879, by Prof. T. R. Jones.

bedded sandstone, about 150 feet; with fragments of Sauroid bones. 3. Red beds: friable, red and purple arenaceous shale, and sandstone, about 600 feet; with Sauroid bones; and some fossil wood in the lower beds. 4. Coal-measures: grey and light-coloured sandstones, generally felspathic, alternating with shales, in which occur coal-seams, and conglomerates, about 1,000 feet; carbonized plant-remains abundant in the sandstones, ferns in the shales; fossil wood abundant; fossil bones very rare. Doleritic dykes penetrate the whole series. The "Stormberg" strata, he says, continue throughout the Drackensberg range, and the series is as strongly marked near Harrismith as in the Stormbergen. The beds lie conformably on red, greenish, and grey shales, with grey sandstones, rich with Dicynodont and other reptilian remains. From the position the coal-measures occupy, it is clear that coal-outcrops will be found right round the base of the Drackensberg, and equally clear that the seams are thicker and the quality better the further they occur to N.E. from the Stormberg. In Natal, at Biggarsberg, is a seam of coal, 8 feet thick, of better quality than the Stormberg coal. In the Transvaal equally thick seams of superior coal are known in the High Veldt. A few outcrops are known in the Orange River State. Properly directed explorations would result in tracing the outcrops through Kaffirland, Natal, the Transvaal, and Orange River State. In the higher parts of Basutoland, and, in fact, along the higher portions of the Drackensberg chain and its spurs, no coal will be found; the seams do not occur at such altitudes.*

* "Report on the Stormberg Coal-field" (1878).

From the Orange River State, Mr. Stowe, F.G.S., reports that the following useful materials occur :—

1. Nodular limestone, such as used in other countries as cement-stone, scattered over various parts of the State.

2. Great beds of old crystalline limestones (siliceo-calcareous rocks).

3. An immense area of country filled with porphyritic rocks, which would vie with granite for durability and beauty.

4. An abundant supply of magnetic and other rich iron-ores, within a convenient distance of the necessary fuel for smelting.

5. A great coal-bed.

In a former report he stated that, judging from the excavations made in the Sand River district, the coal underlying that portion of the country would, at a low estimate, amount to some 145,800,000 tons. We can now safely state that in the new coal-field, since discovered in the Vaal River valley, the minimum quantity would be some 350,000,000 tons ; making a total, in the two coal-beds, of 495,800,000 tons.

From calculations based on those used in England, Mr. Stowe finds that the Orange River State coal-supply would be sufficient to allow of a yearly consumption of more than 6,000,000 tons for a period of 1,200 years !

It is not improbable that, as outcrops of coal in this portion of South Africa show themselves in the Orange River State, along the Vaal Valley, and also in the Transvaal, west of the Drackensberg, associated with the rocks dipping eastward, and as they again appear in the Utrecht Division of the same province, as well as at Biggarsberg (Newcastle) in Natal, to the east of the same

great range, these are all parts of the same great coal-field; the Drackensberg mountains occupying their synclinal trough. If, after proper investigation, such should prove to be the case, the supply of South-African coal will be enormous, throwing the figures above quoted, vast as they appear, completely in the shade.*

* "Friend of the Free State," August 7th, 1879; quoted in "Geol. Mag.," November, 1879.

PART IV.

CHAPTER I.

THE NORTH AMERICAN CONTINENT.

British Possessions.

THE States of America not appertaining to the British Crown have retained possession of by far the greater portion of the coal-producing region of the North American continent. In Canada proper, there exists not a vestige of the coal-formation: and the coal-fields within the boundaries of the British Empire are confined to its outlying north-eastern districts of Newfoundland, New Brunswick, and Nova Scotia, and the borders of the Rocky Mountains. These we now proceed to describe.

NEWFOUNDLAND.

From the survey of the late Mr. Jukes, it appears that there are two small, and, as far as known, not highly productive, coal-fields in Newfoundland; one extending along the eastern shore of St. George's Bay, some distance inland, and the other from Grand Pond to White Bay.*

The formation is similar to that of Nova Scotia, consisting of two members which pass into each other. The

* "Geology of Newfoundland."

lower member consists of red sandstone, red and green marls, with gypsum; the upper, of dark shales, fireclays, sandstones, conglomerate and coal.

NEW BRUNSWICK AND NOVA SCOTIA.

The geological structure and mineral resources of this region have been lucidly described by the late Sir W. Dawson.* From the excellent geological map which accompanies his work, it would appear that nearly one-half of these territories are composed of Carboniferous rocks; but of this less than a third contains productive coal-measures.

The following is the general succession of the Carboniferous series:—

	Thickness Feet.
1. *Upper Coal-series.*—Grey and red sandstones and shales, conglomerates, and a few thin beds of limestone and coal of no economic value	3,000
2 *Middle Coal-series.*—Grey and dark sandstone, and shales, etc., with valuable beds of coal and ironstone; beds of bituminous limestone, and numerous underclays with *Stigmaria*	4,000
3. *Lower Carboniferous* or *Gypsiferous Series.*—Reddish and grey sandstones and shales, over-lying conglomerates; thick beds of limestone with marine shells; and of gypsum ... ... more than	6,000

Fossil Remains.

The fossils of the upper series are composed principally of plants, as *Calamites*, *Ferns*, and Coniferous wood.

In the middle series, representing the middle coal-

* "Acadian Geology."

measures of England, remains of both the animal and vegetable kingdoms appear to be remarkably abundant, and are classed by Dawson as follows:—

Reptiles.—*Dendrerpeton Acadianum*, discovered by the author and Sir C. Lyell, within the upright trunk of a Sigillaria. *Baphetes planiceps*, a large batrachian allied to Labyrinthodon; besides one or more species indicated by their tracks.

Fishes.—*Palæoniscus*, *Holoptychius*, *Megalichthys*, and several other undetermined genera.

Articulata.—*Cypris* or *Cytherina*, several species. *Spirorbis*, either embedded or attached to plants.

Mollusca.—*Pupa vetusta*, the first example of a land shell ever found in the Carboniferous rocks. *Modiola*, *Anthracosia* (Unio), of two or more species.

A large number of plants of European genera, and many of European species.

The Lower Carboniferous series, representing all the strata of England, from the Millstone Grit downwards, contains a reptile, discovered by Sir William Logan; fishes of the genera, *Holoptychius* and *Palæoniscus*. Of Annelides, *Spirorbis;* of Crustaceans, a *Trilobite* or *Limulus;* besides a large series of Mollusca, of the genera *Nautilus*, *Orthoceras*, *Conularia*, *Euomphalus*, *Natica*, *Terebratula*, *Spirifer*, *Productus*, *Cardiomorpha*, *Pecten*, *Avicula*, *Modiola*, *Isocardia*, *Cypricardia:* of Polyzoa, *Fenestrella*, *etc.*, Crinoids, etc.; and a few plants.

CUMBERLAND COAL-FIELD.

This is by far the largest Carboniferous tract, covering an area, according to Professor Rogers, of 6,889 square miles.* It extends along the whole line of coast, and as far inland as the base of a range of mountains which

* "Geol. of Pennsylvania," vol. ii.

stretch along the northern coast of the Bay of Fundy. Its southern limits are the Cobequid Hills. Unfortunately, the surveys of this great coal-field have not tended to raise our expectations of its economic importance, as the greater portion of it appears to be composed of the Lower and Upper Carboniferous series, both of which are destitute of valuable coal-beds.

If economically unimportant, it is far otherwise in a scientific point of view, as, along the coast of the Bay of Fundy, at South Joggins, it displays the finest natural section of the coal formation in the world. The whole series of this district attains a thickness of 14,570 feet, with 76 seams of coal. Of these, 4,515 feet are brought to light in the coast section. The beds rise along the face of the cliffs, clean and fresh, to a height of 150 feet, at an angle of 19 degrees; so that, in proceeding along the coast from north to south, for a distance of about 10 miles, we arrive at constantly newer beds, which at low tide may be traced out from the base of the cliff for a distance of 200 yards. Sir C. Lyell counted 19 seams of coal, and at least ten forests of upright stems of Sigillaria, the longest of which was 25 feet, with a diameter of 4 feet where broken off; they were found invariably based on the upper surfaces of the beds of coal.

In the Cumberland coal-field, the principal coal is the "Joggins Main Seam," consisting of two beds, 3½ and 1½ feet thick. There are also six or seven workable seams at Springhill with a total thickness of 42 feet of coal,* besides several places in New Brunswick, especially a remarkable pitch-like vein called the "Albert Mine," on the Petitcodiac River.

* "Mem. Geol. Survey of Canada." Rep. by A. R. C. Selwyn, F.R.S., for 1870-71, p. 6.

COAL-FIELD OF COLCHESTER AND HANTS.

This district is separated from that of Cumberland by thr Cobequid chain of hills, and has an area of about 200 square miles. It is principally valuable for its limestone and gypsum. The coal seams appear to be all under 18 inches in thickness.

COAL-FIELD OF PICTOU.

This coal-field has an area of about 350 square miles, and is remarkable for containing two very thick beds of coal, the upper 37 feet, and accompanied by three other workable beds having an aggregate thickness of nearly as much more, separated by 157 feet of strata. These seams have partings of inferior coal and ironstone at intervals. The upper bed has been largely worked at the Albion mines; and though there of good quality, has been proved to deteriorate at a short distance both to the north and south of that locality. Recently, however, according to the statement of Dawson, an extension of these great beds of coal has been proved over five new properties, which must contain a workable quantity of 150 millions of tons of good coal; and there is reason for believing that the area is still considerably greater.*

COAL-FIELDS OF RICHMOND AND CAPE BRETON.

The combined areas of these fields may be estimated at 350 square miles. Several workable seams of coal have already been discovered, besides valuable deposits of lime-

* "Geol. Mag.," February, 1867.

stone and gypsum. For our knowledge of the Sydney coal-field we are particularly indebted to Mr. R. Brown, who gives the following synopsis :—The productive measures cover an area of 250 square miles, with a thickness of about 10,000 feet of strata.* Of several very fine natural sections exposed to view along the coast, the most interesting is that to the N.W. of Sydney Harbour, extending a distance of 5,000 yards, and exhibiting a vertical thickness of 1,860 feet of strata. Of these, 34 are coal-seams, combining to produce 37 feet of coal. Four only are workable. The following is the general section of these coals :—

	Ft.	In.
Cranberry Head Top Seam	3	8
Strata	280	0
Lloyd's Cove Seam	5	0
Strata	730	0
Main Seam	6	9
Strata	450	0
Indian Cove Seam	4	8

Valuable coal-seams occur also at Lingan and Bridgeport; one of which, 9 feet in thickness, yields a fine coke, and is esteemed as a gas-coal. Limestone and gypsum also abound; and, on the whole, the mineral resources of Cape Breton county appear very promising.†

In 1903, the quantity of coal raised in Canada was 3,720,000 tons.

* "Journ. Geol. Soc. London," vols. ii and vi. See also Geological Map and Report on the Sydney Coal-field, in Report of Progress of the Geol. Surv. of Canada, for 1875–6, by A. R. C. Selwyn (1877).

† Mr. Brown has published an important treatise, entitled "The Coal-fields and Coal-trade of Cape Breton," with maps and illustrations (London, 1871), giving very complete information regarding the subject on which it treats, to which the reader is referred for fuller information.

Emigrants and settlers would do well to make themselves acquainted with the mineral resources of the districts in which they propose to settle; as they may thus procure a tract of land which may prove, from its mineral wealth, of benefit to themselves and their descendants.

CHAPTER II.

UNITED STATES.

THE great hydrographical basin of the Mississippi and its tributaries is underlaid throughout a greater part of its area by productive coal-measures, with enough coal to supply the whole of that vast continent, were it as populous and as industrious as Britain for a decade of centuries. This great Carboniferous formation was spread originally in one continuous sheet over the whole of Central America, probably from the flanks of the Rocky Mountains to the shores of the North Atlantic, and from the Gulf of Mexico to Newfoundland; and though we are unable strictly to define the original margin and limits of this great coal-generating tract, yet there is reason to believe, as has been pointed out by Sir C. Lyell, that land existed at that period where now rolls the Atlantic; and that the British Islands were connected with America by a chain of islands, or a tract of land, over which the plants of the Carboniferous period migrated and spread themselves in dense forests. Such an hypothesis seems the most satisfactory explanation of the remarkable fact, that the Carboniferous vegetation of America is identical, at least generically, with that of Europe; which could not have been the case under any of the received theories of the distribution of plants and animals, if these regions had been separated by wide barriers of ocean.

Moreover, in tracing the Carboniferous strata, from Texas and Missouri on the S.W. to the Alleghany Mountains and Nova Scotia on the east and north, we find a progressive thickening of the sedimentary materials, such as sandstones and shales, which become both more abundant, and of coarser texture, as we approach the sea-board of the Eastern States. This points to the position of the old land, from which these materials were derived, as having lain somewhere in the North Atlantic; and, combined with the evidence derived from the vegetation, becomes almost demonstrative of the presence of land where now rolls the sea.

The great tract of coal-measures, which was, without doubt, originally connected throughout, has now become distributed into several coal-fields more or less distinct. The late Prof. H. P. Rogers enumerated five of such coal-fields, and estimated their united area at 196,863 square miles,* but a more recent account by Prof. C. A. Hitchcock makes the number of the coal-fields and the combined area considerably larger; as follows:†—

	Sq. miles.
1. New England Basin: anthracite coal, with a maximum of 23 feet of coal, area	750
2. Pennsylvania Anthracite Basin: max. of coal 207 feet‡ ...	434

* "Geol. of Pennsylvania."

† "Geol. Magazine," vol. x, p. 99. The reader will find in Macfarlane's "Coal Regions of America," 1873, a large amount of information extracted from the States Surveys, thrown into a condensed form. There is also a small but very beautiful map of the American coal-fields by M. Jules Marcou, in Peterman's "Mittheilungen," vol. vi (1855).

‡ Mr. P. W. Sheafer estimates the area at 470 square miles, and the thickness of coal at an average of 107 feet.

	Sq. miles.
3. Appalachian Basin. Coal bituminous. This coal-basin ranges through the States of Pennsylvania, Maryland, West Virginia, Ohio, East Kentucky, Tennessee, Georgia, and Alabama. In West Virginia the thickness of coal amounts to 51 feet	63,475
4. Michigan Basin, with 11 feet (max.) of coal	6,700
5. Illinois Basin, ranging through Illinois, Indiana, and Western Kentucky, with 35 feet (max.) of coal ...	51,700
6. Missouri Basin, extending from Iowa to Texas, including parts of Nebraska, Missouri, Arkansas and Indian territory. Area more than	100,000
7. Texas Basin, a branch of the preceding	6,000
Total area more than	229,059

Over the central and western districts, the strata lie regularly, and only slightly removed from the horizontal position ; but on proceeding eastwards, and approaching the chain of the Alleghanies, they become bent ; and ultimately folded and crumpled along lines parallel to the axis of the mountains. Corresponding with this folding of the beds, the coals lose their bituminous properties, and along the western flanks of the mountains occur only as anthracite. The close connection between the crumpling of the coal-seams, and the loss of the volatile constituents of the coal itself, is strongly marked ; for in proportion as we recede from the axis of disturbance, the coal-seams become more bituminous.

The Alleghany Hills consist of a succession of parallel ridges, divided by narrow and deep valleys, corresponding to the folding of the strata. The axis is nearly parallel with the coast of the Atlantic, and reaches at Black Mountain an elevation of 6,476 feet. The geological structure of this remarkable range leads to the conclusion

that it has been formed by the exertion of lateral pressure, acting along the Atlantic side, and forcing the strata towards the west, with a power to which geology affords few parallels. In consequence of the structure of the beds, and the subsequent partial denudation, these mountains contain several small trough-shaped coal-fields, in which the coal has become metamorphosed, and assumes a columnar structure, the axes of the columns being perpendicular to the planes of bedding. There are also springs of pitch and petroleum, of great value; and others of brine, containing 10 per cent. of common salt (chloride of sodium), and small quantities of iodine and bromine. Free carburetted hydrogen also bursts forth at the fountains of the country.*

The thickness of some of the seams of coal is in keeping with the vastness of the coal-fields. In consequence of the thinning away of the sedimentary materials westward, several seams are often brought into contact, and form one mass. Thus in the Bear Mountains there has been formed a seam of 40 feet in thickness, which is described by Sir C. Lyell. It is anthracite, and is quarried from the outcrop into the hill. Sir Charles considers that the thickness of the original mass of vegetable matter, before condensation of pressure, and the discharge of its various gases, may have been from 200 to 300 feet !†

The coal-measures, as in England, rest upon a floor of Carboniferous Limestone, with, in some places, Millstone

* Prof. Rogers. (From a communication to the British Association, 1860.)

† Mr. P. W. Sheafer, in a paper read before the American Assoc. for the Advancement of Science (1879), states that owing to the thickness of the coal-seams in the Anthracite districts, the high angle at which they are inclined, and other causes, the loss in mining of coal is very large, not more than 66 per cent. being taken out of the mine.

Grit intervening; the age of the coal-fields in both countries is therefore identical. The fossils of the Carboniferous Limestone are generically the same with those of Europe—such as *Spirifer*, *Orthis*, *Terebratula*, *Productus*, *Pentremites*, and *Retepora*.

The plants from the coal-measures are *Lepidodendron elegans*, *Sigillaria Sillimani*, *Neuropteris cordata*, *N. Loshii*, *Pecopteris lonchitica*, *Calamites Cistii*, *etc.*, of which all but the second occur in Europe.

*The Triassic Coal-field of Richmond, Virginia.**

Some miles east of Richmond a small coal-field of 26 miles from north to south, and 12 in its greatest diameter, occupies a depression in the granitic rocks of that part of the country.

The Richmond coal-field contains several beds of valuable coal, one of which is from 30 to 40 feet in thickness, highly bituminous, and equal to the best coal of Newcastle.

Other Coal-fields and Lignite Formations.

In Colorado and New Mexico, the late Dr. Hayden and his assistants of the Government Survey report the existence of enormous quantities of coal associated with iron-ore,

* This coal-field was supposed by Sir C. Lyell to be of Jurassic age; but M. J. Marcou, and Dr. O. Heer (on the evidence of the plant remains) refer the beds to the Triassic period, a view supported by Prof. T. R. Jones, from an examination of the fossil *Entomostraca* from this formation. The reader will find the subject ably handled by the last-named author, in the Monog. fos. estheriæ; Palæont. Soc., 1862, p. 84, *et seq.* The late Dr. Oldham considered the Richmond coal-field as probably of the same age as that of the coal-formation of India.

especially along the base of the Raton Hills and Placiere Mountains.* These are now known, I believe, under the general name of "the Laramie Coal-fields," from the geological formation in which the coal is found, and which appears to lie on the borders of the Cretaceous and Tertiary groups.

The most important of these coal-fields extends across the boundary between Colorado and New Mexico, and is described by Prof. J. J. Stevenson as occupying an area of about 2,200 square miles, and contains numerous coal-seams interstratified with sandstones and shales, containing *Halymenites*. The coals are liable to rapid changes in thickness and quality, and are laid open to view in some of the valleys and cañons which traverse the tablelands of that remarkable region.†

Similar beds of coal or lignite are described by Mr. Clarence King as occurring in the Laramie group along the Fortieth Parallel.‡ Deposits of coal are also found in Idaho and Wyoming, which have been opened up to some extent along the line of the Union Pacific Railway, and are described by Dr. F. V. Hayden and his assistants of the American Survey.§

Coal-fields of smaller extent and uncertain age occur, according to M. Marcou, at the sources of the Rio Colorado, in the Utah territory, and on the shores of the Pacific Ocean north of Cape Blanco.||

In Vancouver Island, and on the opposite coast of

* Report U. S. Survey, 1869.

† "American Journ. Science and Art," vol. xviii, 1879.

‡ Report, p. 330, *et seq.* (1878).

§ Eleventh Annual Report, 1877.

|| "Geologische Karte der Vereingten Staaten," in "Peterman's Mittheilungen," 1855.

America, there are extensive deposits of Tertiary and Cretaceous age, bearing beds of lignite and coal, which are extensively worked for the supply of the steamers navigating between Victoria and the Frazer River.* Of this coal that obtained from Nanaimo is admitted to be the best.†

Mr. Isbister describes extensive lignite deposits in the valley of the Mackenzie River, probably of the same geological age as those in Vancouver Island. These strata have been traced by Sir J. Richardson from the shores of the Arctic Sea, along the eastern base of the Rocky Mountains as far south as lat. 52 degrees. The beds of lignite attain a thickness of 9 feet, and are well shown where the Bear Island River flows into the Mackenzie.

Sir J. Hector, who accompanied Captain J. Palliser's expedition in 1857–60, has determined the Geological age of the lignites of North-western America and Vancouver Island to be Cretaceous, though others of inferior quality and of Tertiary age also exist.

The following is a section of the Lignite group obtained by Hector on the bank of the Saskatchewan River, near Fort Edmonton :—‡

* Mr. Bauerman, "Journ. Geol. Soc.," vol. xvi, p. 201.

† For details see Mr. J. Richardson's Report, addressed to Mr. A. Selwyn. Report Geol. Survey, Canada, 1871–2; also, Report of Progress, 1876, p. 160.

‡ For a very interesting account of the coal-fields of the North Pacific Coast, see Mr. Robert Brown's communication to the Edin. Geol. Soc., 1868–9.

1. Superficial sand and gravel.
2. Grey sandy clay.
3. Lignite, 1 foot thick.
4. Shale.
5. Lignite, 2 feet.
6. Clay and sandstone.
7. Lignite, very pure, 3 feet.
8. Concretionary greensand.
9. Lignite, pure and compact, 6 feet thick, with a band of soap-clay, 6 inches thick.

This bottom bed of lignite was analysed by Mr. Tookey at the Laboratory in the Museum of Practical Geology, and was found to contain about 16 per cent. of ash. Very thick beds of lignite have also been observed on the banks of the Red Deer River, a tributary of the Saskatchewan. On the importance to British commerce of the coal deposits in British territory on both sides of the Rocky Mountains, Sir J. Hector lays just stress, showing that they offer a certain inducement towards a route to China and the East by Canada, the Saskatchewan and British Columbia.

California.—According to the statement of Mr. Macfarlane, no true Carboniferous coal has ever been found in California, Oregon, or in any of the territories west of Kansas. The formations of the region bordering the Pacific are of newer age than the Carboniferous, and whatever fossil fuel occurs from Behring's Straits to those of Magellan, consists of lignite.* A fair description of this variety is found at Mount Diablo near San Francisco, Coos Bay in Oregon, Seattle, on Puget Sound; Bellingham Bay in Washington Territory, and in Vancouver's Island. The mines at Mount Diablo are connected with the city by rail. Coal and lignite occur also on Jameson Land, Banks' Land,

* "Coal-Regions of America," p. 561.

and Melville Island. In Albert Land, in lat. 78 degrees, Sir E. Belcher found bituminous schists with coal, and apparently connected with these strata, limestones with *Productus* and *Spirifer*.

*Coal-fields of the North Pacific Coast.**

Mr. R. Brown, F.R.G.S., who has had extensive opportunities of investigation, states that these coal-fields, three in number, extend from the borders of Alaska to California, and belong respectively to the Tertiary, Secondary, and Palæozoic ages; the last being situated in Queen Charlotte's Islands, off the northern coast of British Columbia, and yields anthracite. The Secondary beds are confined to the Island of Vancouver, and they may be a continuation of the Cretaceous strata of Missouri; while the Tertiary coal-fields extend from California northward through Oregon and Washington Territory, touching the southern end of Vancouver Island and British Columbia. The following analysis of the native and imported coals may prove interesting:—

* For a very interesting account of the coal-fields of the North Pacific Coast, the reader is referred to the communication of Mr. Robert Brown, laid before the Geological Society of Edinburgh, 1868–9.

TABLE of Analyses of Native and Imported Coals of the North Pacific (100 Parts).

Locality or Name of Coal.	Specific Gravity.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Percentage of Coke.	Ash.	Remarks.
Imported coals—									
Welsh (Craigola)	1·30	84·87	3·84	0·41	0·45	7·19	85·5	3·24	
Newcastle (Cans Hartley) ...	1·25	79·83	5·11	1·17	0·82	7·86	60·63	5·2	
Scotch (Fordel Splint) ...	1·25	79·58	5·50	1·13	1·46	8·33	52·03	4·00	
Borneo (Labuan)	1·28	64·52	5·74	0·80	1·45	20·75	—	7·74	
Chili (Conception Bay) ...	1·29	70·55	5·76	0·95	1·98	13·24	43·63	7·52	
Sydney	—	82·39	5·32	1·23	0·70	8·32	—	2·04	
Pennsylvanian Anthracite ...	—	90·45	2·43	—	—	—	—	4·67	S. and N., 2·45.
Native Coals, Cretaceous—									
Nanaimo (V. I.)	1·24	66·93	5·32	1·02	2·20	8·70	—	15·83	
Koskeemo (V. I.)	1·32	66·15	4·70	1·25	0·80	13·50	—	13·60	Average specimens.
Native Coal, Tertiary—									
Bellingham Bay (W. T.) ...	—	47·63	—	—	—	—	—	2·15	Bitumen, 50·22.
Clallam Bay (W. T.) ...	—	46·40	—	—	—	—	—	2·63	Vol. matter, 50·97.
Coose Bay (Ogn.)	—	46·54	—	—	—	—	49·73	3·19	Vol. matter, 50·27.
Monte Diabalo Cal.	—	50·00	—	—	—	—	—	4·00	Vol. bit. matter, 46.
Native Anthracite—									
Queen Charlotte Islands ...	1·46	71·20	—	—	—	—	—	6·43	Moisture, 5·10. Vol. comb. matter, 7·27.

In Disco Island, and the adjoining coast of Greenland, in lat. 70 degrees, beds of coal accompanied by plant-remains were found, and specimens brought home by Sir F. L. M'Clintock, and subsequently by Mr. Whymper. These plant-remains, on being submitted for examination to Prof. Heer, of Zurich, were pronounced by him to be referable to the Miocene stage of the Tertiary period.*

TRINIDAD.

This Island has long been celebrated for its lake of mineral pitch; but, besides this, it contains beds of coal and lignite, likely to become of considerable economic importance. The very successful survey by Messrs. Wall and Sawkins, the Report of which has been published,† puts us in possession of all that is at present known. The strata with which the beds of coal are associated belong to the Tertiary period, and are very widely distributed. In the middle of the island there is a thickness of 6 feet 10 inches of workable coal, in two beds; and in the southern section, double that amount in three beds. The strata, consisting of shales, sands, and carbonaceous clays, which contain these coal-seams, reach a total thickness of about 2,000 feet. They range across the island in parallel zones, and present interesting sections along the coast, very faithful details of which are presented by Mr. Wall. The asphalte is almost invariably disseminated in the newer Parian group, which contains the beds of lignite and a large amount of vegetable matter.

* Heer's "Flora Fossilis Antarctica"; also the "Geol. Mag.," July, 1869.

† "Report on the Geology of Trinidad," "Mem. Geol. Surv.," 1860, with maps and sections.

The same Tertiary formations, under the term "Newer Parian," have been traced by Mr. Wall on the neighbouring coast of the Continent, and are known to contain lignite and coal at Piaco on the Orinoco, and in the provinces of Barcelona and Coro. Mineral pitch is also found in these strata.*

It is proper to observe that these Tertiary lignites are inferior in economic value to the coal of the true Carboniferous formations of Europe and North America; and so long as these latter are shipped in sufficient quantity into the West Indian Islands, the fossil fuel of Trinidad is not likely to be largely worked.

* Mr. Wall, Journ. Geol. Soc., vol. xvi.

PART V.

CHAPTER I.

COAL-FIELDS OF SOUTH AMERICA.

Republic of Brazil.—The Province of Rio Grande do Sul, at the southern extremity of this great territory, is now known to be exceedingly rich in mineral fuel. According to the observations of Mr. N. Plant,* there are three distinct coal-basins contained within the limits of lat. 30 degrees and 32 degrees south, long. 51 degrees and 54 degrees west, which are separated from each other by rolling hills of granite and schist, with trachytic and basaltic rocks. The largest of these basins occupies the valleys of the Jaguarao and Candiota, and the strata, consisting of sandstone at the top, and shale, coal, and limestone below, dip southward at an angle of 10 to 15 degrees.

The following section is exposed in the escarpment of the Sierra Partida, in this basin, as given by Mr. Plant; the beds in descending order:—

* Geol. Mag., No. 58 (April, 1869).

No.		Ft.	In.
1.	Ferruginous sandstone	25	0
2.	Shale (coaly)	9	0
3.	Sandy shale...	5	0
4.	*Coal*	3	0
5.	White shale with plants	5	0
6.	*Coal*	11	0
7.	Parting of blue clay	2	0
8.	*Coal*	17	0
9.	Shale with fossils	9	0
10.	*Coal*	25	0
11.	Shales with ironstone and ferns, resting on sandstone.		

The second basin lies in the valley of the São Sepe, one of the tributaries of the River Jacuahy, in about lat. 30° 20′, long. 53° 30′. Two distinct beds of coal, one 7 feet, and the other 14 feet thick, appear in this locality, underlying sandstone, apparently the same as that which overlies the coal of the Candiota valley.

The third basin is near the town of São Jeronymo, on the banks of the Jacuahy, lat. 30 degrees, long. 51° 30′. Here the coal has been for some time extensively worked by Mr. J. Johnson. The sections of the strata show deposits similar to those of Candiota. At a depth of 19 yards is a bed of bituminous coal 6 feet thick, below which are others interstratified with shales and ironstone.

Carboniferous deposits also occur in the province of Santa Catherina. About 45 miles N.W. of the seaport of Lagana, the basin is intersected by the River Tubarao and its tributaries. In this basin, five seams from 18 inches to 10 feet have been met with, underlying a sandstone formation.

Uruguay.—The coal-bearing formation of Southern Brazil is continued into this Republic, and the succession

of the beds is stated by Mr. Plant to be similar to that above described. Along the head waters of the Rio Negro beds of shale and coal are overlaid by a thick deposit of sandstone.*

Geological Age of the South Brazilian Coal-formation.—The plant-remains from the shales associated with the coal-seams of Candiota, were submitted to Mr. W. Carruthers, F.R.S., of the British Museum, who has been able to determine three species, and to recognise more vaguely a number of other forms, all of which belong to Palæozoic genera, while the species occur in the coal-measures of Great Britain. The genera observed are *Flemingites* (Carr.), *Odontopteris*, and *Næggerathia*.† It would appear from this, that the formation is of true Carboniferous age.

The existence of these deposits of mineral fuel is calculated to be a source of considerable wealth to a portion of South America.

Chili.—Tertiary strata, containing beds of "brown-coal," are found along the coast of Chili, forming several little detached basins, and resting on a basis of metamorphic schists and intrusive rocks.‡ The most important is that lying between Conception and Valdivia, which contains the two largest collieries of the country, those of Coronel Puchoco and Lota; from which the best coal is derived.

According to the report of Mr. Bollaert, the Lota coal is largely used in the steam-navigation of the Chilian coast,

* Geol. Mag., April, 1869 (150).

† Geol. Mag., April, 1869, 151-6 (with plate).

‡ We have accounts of these strata by Mr. C. Darwin, "Geological Observations in S. America," 1864; by Mr. W. Bollaert, "Observ. on the Coal-formation of Chili," Journ. R. Geol. Soc., xxv, 172; and by Messrs. G. A. Lebour and W. Mundle, Geol. Mag., vol. vii, 499 (1870).

as also in copper-smelting, iron-foundries, and for domestic purposes. The Lota coal-field is estimated to contain 40 millions of tons, and the Coronel, double that quantity.

A detailed section of the coal-series at Coronel is given by Mr. W. Mundle, throughout a depth of 587 feet, which shows a series of sandstones and shales, with nine seams of coal, or lignite, some of which are workable. The eighth seam from the top, nearly 5 feet in thickness, is described as a "very good, hard, and clean coal," which, however, it ought to be remarked, is inferior in quality to true Carboniferous coal of Britain or America. The following are the analyses of these coals :—

—	Talcahuano (Admiralty).	Lota, Dr. Playfair.	Lota (First Seam), Mr. Abel.
Ash	6·92	5·68	2·05
Carbon	70·71	78·30	83·70
Hydrogen	6·44	5·30	1·02
Oxygen	15·93	8·37	13·23
Sulphur		1·06	
Nitrogen		1·29	
	100·00	100·00	100·00

On the age of these beds some difference of opinion exists; along with representatives of Tertiary genera, such as *Voluta*, *Bulla*, etc., there are Cretaceous genera, such as *Ammonites* (fragments of one specimen), and *Baculites*. On this ground, M. A. D'Orbigny has contended for the Cretaceous age of these carbonaceous deposits, while Mr. C. Darwin thinks it to be one "verging on the commencement of the Tertiary era."

PART VI.

CHAPTER I.

THE following is the annual production of coal in various countries :—*

1. BRITISH EMPIRE.

Country.	Year.	Tons.
United Kingdom	1903	230,334,000
British India	1902	7,424,000
Dominion of Canada	1903	7,140,000
New South Wales	1903	6,355,000
Victoria	1902	225,000
Western Australia	1903	133,000
Queensland	1903	508,000
Tasmania	1902	50,000
New Zealand	1902	1,363,000
Cape of Good Hope	1902	166,000
Natal	1903	714,000
Transvaal	1903	2,016,000‡
2. FOREIGN COUNTRIES.		
Russian Empire	1903	15,000,000†
German Empire	1903	116,638,000‡
Belgium...	1903	23,912,000‡
France	1903	34,318,000‡
Spain	1903	2,701,000‡
Austria	1903	11,498,000
Hungary	1902	1,163,000
Japan	1902	9,702,000
United States	1903	320,983,000
Total for all countries...	—	785,647,000

* From Returns of the Board of Trade, July, 1904.
† Estimated. ‡ Provisional.

If we compare the above statement with that given in the last edition of this work for 1877–9, when the estimated quantity amounted to about 289 millions of tons, we shall have some idea of the enormous expansion of the world's production during the last quarter of a century, which may be taken as an index to the increase of the industrial populations, of commerce and of manufactures. The increase amounts to about 18 millions of tons per annum. Foremost amongst these advancing countries is the United States of America. At the time referred to, the production of these states was less than half the quantity of that of the British Isles; at the present time not only has the output of coal come up to that of the United Kingdom, but it has outstripped it by nearly 100 millions of tons,* a marvellous evidence of the industrial enterprise of our trans-Atlantic rivals, because this over-leap has taken place while the British coal produce has itself progressed.

This progression will be apparent from the following table, commencing with the year 1870:—

Output of Coal from the Coal-fields of the United Kingdom since 1870.†

Year.	Tons.
1870	110,431,000
1871	117,352,000
1872	123,497,000
1873	128,680,000
1874	126,590,000
1875	133,306,000
1876	134,125,000

* Really 90,649,000 tons.

† "Mineral Statistics U. K. for 1895–6."

Year.	Tons.
1877	134,180,000
1878	132,612,000
1879	133,720,000
1880	146,969,000
1881	154,184,000
1882	156,500,000
1883	163,737,000
1884	160,758,000
1885	159,351,000
1886	157,519,000
1887	162,120,000
1888	169,935,000
1889	176,917,000
1890	181,614,000
1891	185,479,000
1892	181,787,000
1893	164,326,000
1894	188,278,000
1895	189,661,000
1896	195,361,000
1897	202,130,000
1898	202,055,000
1899	220,095,000
1900	225,181,000
1901	219,047,000
1902	227,095,000
1903	230,334,000*

Average increase of output during the above period is 2·34 per cent.

From these returns it will be seen that although there has been a general advance it has not been continuous or uniform; on the contrary there have been years of relapse

* The value of the coal produced in U.K. in 1900 was £121,653,000; in 1901, £102,487,000; in 1902, £93,521,000; and in 1903, £88,228,000. It will be seen that the value of the coal supply is not proportionate to the output; as in 1903, when the output was greatest, the value was less than in the year 1900, when the quantity was less by about 5 millions of tons.

such as in 1874, 1878, 1884, 1892 and 1893, with some others of less importance. Of these the most serious, and to a certain extent disastrous, was that of the year 1893, when a great strike and lock-out occurred in the Midlands. Collieries in the counties of York, Derby, Nottingham, Stafford, and Warwick were the chief sufferers; the collieries having stopped working, miners being thrown out of employment and reduced to penury, while trade was utterly disorganised in the districts affected. Employers as well as employed were heavy losers, while the mines themselves fell into disrepair. Nor do the results end here; for it often happens that trade is diverted from the district in which the stoppage occurs, and may never return. Meanwhile, coal-pits which have been kept open by their owners with little or no profit in the hope of better times, are, under such conditions, often permanently shut down. It is much to be desired that, for the regulation of wages, the system of the sliding scale, which has worked so well for the advantage of the community in South Wales and Durham, should be extended throughout the whole of the mining districts of Great Britain, by which the miners' wage was regulated by the average price of coal; but it must be remembered that questions of rate of wages are not the only ones which are sometimes the cause of dispute in mining districts.*

* For the regulation and closing of disputes about wages the Conciliation Board is now constituted, and with the happiest results.

CHAPTER II.

SUGGESTED SUBSTITUTES FOR COAL.

Waterfalls.—As the production and use of coal were not the only subjects entrusted to the Commission for investigation and report, a large amount of information was obtained from witnesses, upon those agents which may be considered, to some extent, as the rivals of coal in the development of heat and power, such as water falling from higher to lower levels, petroleum, peat, and other kinds of fuel; to these and kindred subjects we shall devote the present chapter, referring the reader to the reports of the evidence for fuller details.

Water-power.—The fall of water—the agent by means of which the force of gravity can be utilised—for the production of mechanical energy is a subject of the greatest interest and importance, as this force is everywhere present and unfailing wherever water in motion is available. Wherever water descends there we have power capable of being utilised, either directly by means of mechanical appliances, or by ultimate conversion into electrical energy; it is in this latter aspect that we are called upon to deal with it here. Electricity, which is really not a source of, but only a distributing agent for, power, may be obtained from the fall of water in rivers or in the tides; but this latter agency may be neglected, on account of not only the engineering difficulties that would have to be faced in each

case, but owing to the enormous surface of water which would have to be impounded, and to the small extent of the rise and fall of the tides. We are, therefore, obliged to have recourse to the waterfalls, of which, although we have no Niagara, there are many in the British Islands not utilised up to the present to the extent of which they are capable.

Interesting evidence on the subject was brought before the Commission by Prof. George Forbes, F.R.S.,* who had personally visited a large number of possible or actual localities in almost every part of world where waterfalls might be, or were, in use for the development of electrical power. Necessarily, the Falls of Niagara take the first place, where operations are in progress for generating electricity to the extent of 100,000 horse-power throughout the year. Here the facilities are specially available owing to the vast extent of the Great Lakes of America, which can keep the flow of water over the falls absolutely constant throughout the year. Another great source of power is the Cauvery Falls in Mysore; which, however, notwithstanding their great volume, can only be utilised during part of the year owing to the absence of storage capacity; and lastly the Victoria Falls of the Zambesi, which have a fall of 400 feet, but which are subject to great reduction of power in dry seasons; though in time of flood they are capable of generating power, calculated by Prof. Forbes, at about six times that of the Niagara.

In Switzerland where at Zurich, Geneva and other places on both sides of the Alps, water power is very largely employed for generating electrical power—the absence of storage lakes is often compensated for by the melting of

* Forty-fourth Meeting, February 17th, 1904.

the snows in summer, so that the machinery can be kept constantly at work.

But when we come to the British Isles we are met almost everywhere by this disadvantage that our streams are liable to fall so low in volume, or absolutely to become dried up in summer time; and where, without the construction of costly embankments, the water power is liable to cease altogether, or to become so reduced as to be valueless. This element of cost in the construction of reservoirs makes competition with coal as a source of power impossible in most places at the present time. Prof. Forbes has given much consideration to the possibilities of the United Kingdom as regards development of power by water, and has come to the conclusion that at the present day, owing to the abundance and cheapness of coal, the only place where one can look for a large development of such power is in Scotland; and he points to the physical conditions of Loch Ness in Inverness-shire and Loch Ericht, in Perthshire, as those offering the most advantageous sites for electrical appliances in the future.

As regards the falls of the Clyde, which, when in flood, give a large body of water, they might be made to generate something like 8,000 horse-power, but only by the construction of large and expensive embankments. In Ireland the falls of the Erne at Belleek, draining as they do a lake 15 miles in length by 3 in greatest breadth, with a large drainage area in the Upper Erne, seem capable of supplying continuously a large amount of power, as do those of the Shannon below Lough Dearg and the Liffey at Lucan.

Doubtless there are other places where by a small application of engineering skill water might be made available in the mountainous districts of our islands; yet it

will be seen that owing to absence of sufficient area and low elevation of the sources of our streams, and the non-existence of snow-fields as they occur in the Alps and Norway, the application of water-power is necessarily limited, and the demand for coal has little to fear from the extensive introduction of electrical power generated by the upland waters of the British Isles.

Another country possessing large reserves of power from waterfalls is Norway, as all who have visited that splendid country must be aware.

Peat.—The use of peat as a fuel may be referred to, but only briefly, as a source of heat and power. For although there are large areas of peat in these islands, especially in Ireland, all attempts to convert it into fuel in competition with coal have been unsuccessful, owing to the large quantity of water it contains, and the cost of compressing the material into briquettes. The experiment has been made more than once in central Ireland, but unsuccessfully, owing to the above cause, together with the fact that the proportion of ash is excessive. One ton of good coal would produce at least four times the heat of a similar weight of peat.

Petroleum.—The next and, indeed, the most important substitute for coal, is petroleum; which, like coal, is a natural product of the earth's crust, and has within the last half century become very largely a source of heat and power; being used for driving machinery both by land and sea, the manufacture of gas and other uses, and which is obtained at a large number of localities all over the globe, but chiefly in sub-tropical regions.* The great petroleum

* On the production and application of petroleum valuable evidence was given by Dr. Boverton Redwood, Consulting Adviser to the Corporation of

producing countries of the world are Russia, United States of America, Galicia, Eastern Archipelago, Roumania, India (Burma and Assam), Japan, Canada, Germany (Hanover and Elsass), Peru, Hungary, and Italy. The above are arranged in order of quantity of production; Russia with its great Bacu and Grozni fields taking the lead with a production of nearly 3,000 millions of Imperial gallons per annum; and next to Russia come the United States with a production of 2,427,650,000 gallons.*

The British Isles, so rich in coal of the highest quality, appears to be nearly destitute of petroleum as obtained directly from the strata, though several formations supply mineral oils by distillation. The most important of these are the Carboniferous Oil Shale of Scotland, and the Kimmeridge Clay of England, but it is only in the former that manufacture of mineral oil is carried on at the present day, as at Boghead near Edinburgh. In 1901 the quantity of oil shale raised was 2,354,356 tons, giving, at the rate of 30 gallons of oil per ton, 70,630,680 gallons yearly.

The world's production of petroleum may be judged by the following quantities, given by Dr. Redwood, of which the following is an abstract:—†

London, at the 22nd Sitting of the Commission on April 28th, 1903; accompanied by tables of supply, etc.

* The above is the quantity given by Mr. Redwood, but in the Returns supplied by the Board of Trade, August, 1904, p. 49, the output of crude petroleum for 1902 is 3,105,599,000 Imp. gallons, that for 1903 not being given.

† Table A, 2 Rep., p. 193.

Production of Petroleum for 1901 *in Imperial Gallons.*

Russia	2,928,395,290
United States of America... ...	2,427,650,334
Galicia	117,979,782
Eastern Archipelago	106,311,958
Roumania	50,658,525
India, especially Burma	50,075,117
Japan	25,502,168
Canada	24,670,520
Germany	10,801,413
Peru...	2,611,455
Hungary	854,873
Italy	618,947
Barbados	7,200
Total	5,746,139,573

Dr. Redwood illustrates the magnitude of the world's supply and consumption by the idea of a rectangular cistern about two and a-half times the height of St. Paul's Cathedral and of similar length and breadth, which would be required for storing one year's supply.

Notwithstanding, however, the prodigeous supply of mineral oil which is thus annually drawn from the strata, its importance as a substitute for coal is almost insignificant for, according to the statement of the same authority, it would only be an equivalent of about 2·8 by weight per cent. of the present coal consumption.*

From the above statements it will be seen that notwith-

* Dr. Redwood's expression is, "if you double the existing output of petroleum in the world it would only be an equivalent of about 5 per cent. of the present coal consumption." Rep., p. 210. The output of petroleum in the world at 245 gallons per ton would amount to 23,453,141 tons; but as the calorific value of petroleum is weight for weight nearly twice that of coal, it would represent about 44 million tons of coal, a small proportion of the world's produce.

standing the frequent expression that "when coal is exhausted some other substitute will be found to take its place;" that substitute still remains to be found. The event, however, is so far distant that we need not greatly concern ourselves with it. The investigations of the Coal-Commission have made it clear that the exhaustion will be arrived at in the remote future, and the conclusion of the Commissioners is that "coal is our only reliable source of power, and that for it there is no real substitute."

AVERAGE PRICES OF COAL AT THE PIT'S MOUTH.

Amongst the interesting particulars published from year to year by the Department of the Board of Trade, are those giving the average value or price of coal for each year, and also the quantity of coal produced *per capita* of the population of several countries. In the following abbreviated tables we give the results:—

Average Value per Ton of Coal for the Years 1899 *to* 1903.*

Country.	1899.	1900.	1901.	1902.	1903.
	s. d.	*s. d.*	*s. d.*	*s. d.*	*s. d.*
United Kingdom	7 7	10 9¾	19 4¼	8 2¾	7 8
United States ...	4 8½	5 4	5 6½	5 8¼	6 6¾
Germany... ...	7 9¼	8 10	9 4	8 10	8 7½
France	9 11¾	12 0	12 7½	11 8¾	—
Belgium	9 11¼	13 11¼	12 2¼	10 6¾	—
Spain	7 6	7 7¾	9 0	7 11¾	—
New South Wales	5 9	6 1	7 4	7 5	7 4
Japan	6 10½	6 8¼	6 0	—	—
British India ...	4 2½	4 4½	4 0	3 8	—

* Returns, Board of Trade, p. 18.

Perhaps the most remarkable point in the above returns is the very low figure at which the price of coal is quoted for British India. At the present time there is absolutely an excess of production over demand, although some of the seams in the Jherria and Chasnulla district are of good quality and easily mined ;* this latter fact, together with the cheapness of labour, is probably a main cause of the low price of the mineral.

Quantity of Coal produced per Head of the Population in the United Kingdom and other Countries for the Years 1883, 1893, *and* 1903.

Countries.	1883.	1893.	1903.
	Tons.	Tons.	Tons.
United Kingdom	4·62	4·27	5·44
United States	1·92	2·45	3·99
Canada	0·38	0·70	1·29
New South Wales... ...	2·93	2·68	4·44
Queensland	0·36	0·61	0·28
Germany	1·23	1·45	1·98
Belgium	3·18	3·10	3·42
France	0·55	0·66	0·88

From the above table it will be seen that the United Kingdom stands at the head of those countries where the largest proportion of coal to the population is raised ; New South Wales comes next, and then the United States and Belgium. Apart from the demands of steam shipping, the consumption of coal per head is found in the highest proportion in those countries where steam traction and

* An excellent map of the Jherria coal district, with the outcrops of the seams, has been published with the number of the "Colliery Guardian," September, 1904.

machinery worked by steam are mostly in use, and the lowest in those countries where machinery is, comparatively, but little used. Both in France and Germany the consumption per head appears small; but in these countries large quantities of fuel of other sorts, such as turf, lignite, wood and denatured spirits are also in use.* In Sweden and the Russian Empire the proportion is necessarily exceedingly small, as the former country is destitute of coal while in Russia the coal-fields are restricted to the southern part of that vast empire bordering the Lower Don.

* Mr. H. Llewellyn Smith. "Returns," p. 11.

CHAPTER III.

EXPORT OF BRITISH COAL.

SINCE the preparation of the last edition of this work, the export of British coal has gone up "by leaps and bounds," and has become of such importance that it is necessary to devote a special chapter to a review of the subject. During the sittings of the recent Royal Commission a large amount of important evidence was given by colliery proprietors, coal merchants and exporters, as also by representatives of trade in foreign countries, which will well repay careful perusal by those interested. The subject has also been ably handled by Mr. D. A. Thomas, M.P., in an address delivered before the Royal Statistical Society,* and to this address, by his kind permission, I am indebted for much of the details about to be given.† It need scarcely be stated that the question of retaining the export duty was very largely dealt with on these occasions, and it was clear that there was some difference of opinion on the subject; like most fiscal questions, there is much to be said on both sides.

* Meeting on May 19th, 1903.

† The following gentlemen, amongst others, gave evidence on this subject before the Commission:—Mr. F. Oppenheimer, H.M. Consul-General, Frankfort; Mr. M. C. Gurney, H.M. Consul-General, Marseilles; Mr. H. Turing, H.M. Consul, Rotterdam; Mr. T. R. Mulvany, H.M. Consul-General, Düsseldorf; Mr. F. P. Rhodes, Mr. A. C. Briggs, Mr. John Bennett, Mr. E. C. P. Hull, Mr. Evan Williams, Sir J. Joicey, and Mr. E. W. Taylor.

The great importance of the question will be appreciated from the statement of Mr. Thomas, that between the years 1850 and 1900, while the quantity of coal produced in the United Kingdom and retained for home consumption has rather more than trebled, or *per capita*, a little more than doubled, the export, including coal shipped for the use of steamers engaged in the foreign trade, has grown fifteen-fold, and increased from a proportion of 6·8 per cent., to one of 26 per cent. of the total output. This will be apparent from the following table.

Statement showing the Growth of the Export of Coal compared with that of Production, etc., from 1850 *to* 1900.

Year.	Production of Coal in the United Kingdom.	Export of Coal, Coke, and Patent Fuel, including Bunkers.	Percentage of Export to Production.	Remaining for Home Consumption.	Consumption per Head of Population.	Total Value of all Exports.	Value of Coal Exports.
	Million tons.	Million tons.		Million tons.	Tons.	Million £'s.	Million £'s.
1850	56·0*	3·8†	6·8	52·2	1·91	71·4	1·4
1860	80·0	8·4†	10·5	71·6	2·49	135·8	3·7
1870	110·4	14·1†	12·8	96·3	3·11	199·6	6·7
1880 ..	147·0	23·9	16·3	123·1	3·56	223·0	10·8
1890	181·6	38·7	21·3	142·9	3·81	263·5	23·9
1900 . ..	225·2	58·4	25·9	166·8	4·08	291·2	48·3
1903‡	230·3	63·8	30·6	166·5	3·93	—	—

* Estimated.

† Bunker coal not added to total values, but included here and estimated to be of the same average value per ton as exported coal.

‡ Added by the author.

Mr. Thomas brings down his figures to the year 1900, up to the time available at the date of his communication, but in the three years following, from 1900 to 1903, the proportion of export has increased to over 30 per cent. of the

increased output during that period. The distribution of this important commodity to different countries will be of interest at this stage; for the year 1903 the distribution is as follows:—

Total Quantity of Coal, Coke, and Patent Fuel Exported during 1903 *to Various Countries.**

	Tons.
France	7,122,575
Spain	2,155,731
Italy	6,424,608
Russia	2,510,100
Sweden...	3,135,304
Norway...	1,479,768
Denmark	2,345,687
Germany	6,118,323
Egypt	2,174,620
Brazil	939,170
Argentine Republic	1,130,912
Other countries	11,085,902

Thus it appears that almost every country in the world is dependent, to a greater or less degree, on Great Britain for its coal supply—even those which, like France and Germany, are possessed of large coal-fields of their own.

The great importance of the export of coal arises not only from the amount, which reached, in 1903, 44,950,000 tons, and a still larger figure if we include the by-products consisting of coke and patent fuel, but from the extent to which it gives employment to our shipping and carrying trades. As 80 per cent. of our total exports consist of this mineral, it is by far the most important of all our exports; and employs a vast number of vessels trading from our ports

* Board of Trade Returns, August, 1904.

situated on the Humber, the Tees, the Tyne and Forth on the eastern coast, as also from the Clyde, the Mersey and the Severn on the western. And there is yet another important feature of the subject tending to show that, in an indirect manner, it encourages the import of goods from foreign countries by reducing the cost of transport.* Coal, from its weight, makes an excellent ballast for ships, so that vessels carrying goods from abroad can load with coal either for the return voyage, or for some other port.

But unquestionably the great demand which exists for the supply of British coal in foreign parts is due to the variety and excellence of its qualities. As steam coal for naval purposes, it has established a reputation all over the world; so that down to the present time even countries situated east of Suez and the Red Sea are being supplied with British coal, especially the "steam coal" from South Wales, owing to its special qualities for giving great heat, and absence of smoke when burning. But, as pointed out by Mr. E. C. P. Hull, in his evidence before the Commission, the supply to the eastern ports shows a tendency to decrease owing to the growing production of Indian coal, which is making, in recent years, material and rapid progress.† The amount of British coal estimated by the same authority as being used by British shipowners in foreign ports—for "bunker coal" is not less, possibly more, than 5,000,000 tons annually, of which Port Said takes 1,250,000 tons; the Atlantic Islands, including Madeira, Las Palmas, Grand Canary and St. Vincent, about 1,000,000 tons, and the eastern ports, 500,000 tons.

* This point was brought before the Commission very clearly by Mr. Emerson Bainbridge. "Evidence," December 17th, 1903.

† "Evidence," December 17th, 1903.

Steam Coal.—The chief sources of "steam coal" are the north-east of England, and South Wales; the former shipped from the Tyne and Tees, the latter from Cardiff and adjoining ports. In composition, steam coal is semi-bituminous, occupying a position between anthracite and bituminous coal; and thus by the large proportion of carbon, on which its heating power mainly depends, the absence of bitumen which is smoke producing, and the small proportion of ash, it is in special demand for use in the Royal Navy as well as for merchant vessels plying to various parts of the world.* The following table of analyses supplied by Mr. Joseph Shaw to the Commission is here inserted:—

Analyses of Typical Coals in the South Wales and Monmouthshire Coal-fields.†

Locality.	Fixed Carbon.	Volatile Matter.	Sulphur.	Ash.	Water.
HOUSE COAL.					
1. Rhymney Valley, Brithdir Seam	69·60	24·58	1·78	3·56	·48
2. No. 3 Rhondda	71·25	26·00	·85	·90	1·00
STEAM COALS.					
3. Ebbw Vale	75·69	20·40	·71	2·53	·67
4. Ocean Harris	83·40	12·12	·68	2·80	1·00
5. Aberdare Four-Foot	83·10	12·44	·74	3·34	·38
ANTHRACITE.					
7. Swansea Valley Big Vein ...	90·37	4·51	·82	2·90	1·40

References:—No. 1 and 5, Powell Duffryn Coal Co.
,, 2, Glyn Colliery Co.
,, 3, Analysis by J. W. Thomas, F.C.S.
,, 4 and 7, Analyses by L. J. Davies, F.C.S.

* During the great war now proceeding between Russia and Japan, the demand for Cardiff coal on the part of both these countries has been excessive.

† See p. 401.

Notwithstanding, however, these important qualities, which have, up to the present, enabled merchants of Welsh steam coal to export large quantities to India, Ceylon, Singapore, Shanghai, and Japan at a profit, even with the necessarily high freights, the tendency is for these eastern countries to depend to a larger extent on their own resources, chiefly those of India; and thus the Suez Canal is becoming the parting of the ways between the coal traffic of the eastern and western hemispheres.

EXPORT OF STEAM COAL FROM SOUTH WALES.

It will afford some idea of the great demand for Welsh "steam coal" in foreign parts, and for bunkering at coaling stations, when the following returns are considered. The principal ports in South Wales for the export of this class of coal are Cardiff (including Penarth and Barry Docks), Llanelly and Swansea; and I here give the results for the three decennial years and that of 1903:—

Port.	1870.	1880.	1890.	1900.	1903.
Cardiff	2,357,182	4,991,317	9,424,042	13,383,319	14,389,201
Llanelly	118,354	75,874	132,248	205,126	227,093
Swansea	612,643	811,098	966,623	2,093 209	2,312,005
Total ..	3,088,179	5,878,289	10,522,913	15,681,754	16,928,299

Thus it will be seen that the output from these three ports has increased five and a-half times in the 33 years, dating from 1870, the year of the former Royal Commission; and notwithstanding the export duty of 1*s.* per ton during the years 1901, 1902, and 1903, there was a con-

tinuous increase in the exports during those years from the above ports in South Wales.

Estimated Quantity of "First-class Steam Coal" in the South Wales Basin.—Sir W. T. Lewis, the Commissioner entrusted with reporting on this coal-basin, having been requested to produce an estimate of the quantity of coal still remaining for use, such as is supplied to the Royal Navy, has furnished us with the following returns, which will be scanned with interest by the public. He ranges the whole under three divisions:—

1. That remaining unworked in collieries on "the Admiralty List."

2. Coal of similar quality in collieries not at present on "the Admiralty List."

3. Coal of similar quality in unlet areas.

There are 24 colliery companies in South Wales at present on "the Admiralty List," and the total resources of steam coal at the end of 1901 in seams of 1 foot and upwards, of the required quality for use in His Majesty's Navy, are as follows:—

	Tons.
No 1 in the above list	3,240,182,734
,, 2 ,, ,, ...	174,793,547
,, 3 ,, ,, ...	521,681,129
Total	**3,936,657,410**

If it should be considered by some persons, of whom the author is one, that seams of a less thickness than 20 or 24 inches in thickness ought to have been omitted from the above estimates, a considerable reduction would have to be made by them on the total amount.

The Export Duty on Coal.—From the amount of opposi-

tion which has been evoked by the export duty of 1*s.* per ton on large coal, it might be supposed that this was an unprecedented impost; but such is not the case, as Mr. Thomas has abundantly shown. It appears that as far back as the reign of Edward II, there was an export duty on coal shipped to France; and in 1783 there was an export duty from France of 5*s.* per ton, which was condemned by Adam Smith. The nineteenth century opened with a duty of 1*s.* 6*d.* per ton on coal shipped to the colonies, and 7*s.* on coal shipped to foreign countries in British built vessels, and 11*s.* if exported in foreign built vessels, and 10 per cent. additional on the amount of duty. These duties were, however, repeatedly modified, and were ultimately abandoned; so that from August 14th, 1850, to the end of the century, coal was exported free of duty.* From the above details it will be seen that the country had become quite accustomed to an export duty; probably for the two-fold purpose of making the foreigner contribute to our revenue, and of preserving our supplies for our own use and service.

The above objects for imposing an export duty are, in the opinion of a large number of persons, still in force; and consequently, when, in 1901, the Chancellor of the Exchequer having great need of money to meet the heavy demands of the Budget, naturally turned his attention to coal as a valuable asset for the purpose of raising revenue, and imposed a duty of 1*s.* per ton on large coal exported, small coal and dust escaping the tax. It is not my intention to detail the numerous reasons given by witnesses before the Royal Commission in favour of the repeal of the tax; but

* Details of these various changes are given by Mr. Thomas in the paper above. "Trans. Roy. Statistical Society," May 19th, 1903.

I may mention that the most urgent was in consequence of the competition of foreign coal production, especially that of Westphalia, and the exceptional facilities given on the part of the German Government to carriage by rail from the mines to the various points of destination.* Notwithstanding, however, these drawbacks, as affecting the British exporter, it appears that the duty has not seriously affected the quantities sent abroad; on the contrary there has been an increase in the export trade, as will appear from the following returns:—

In 1900, the quantity exported was 44,089,000 tons,† in 1901, before the tax became operative, the quantity fell to 41,877,000 tons; in 1902, when the effect of the tax had become operative, the quantity exported rose to 43,159,000 tons, and in 1903, it reached 44,950,000 tons, exclusive of coke and patent fuel.‡ There has, therefore, been a steady increase in the export trade since the tax was imposed; and, however this may have affected the colliery owners and exporters, it has benefited the community by bringing in revenue to the Exchequer—at this period badly in need thereof.§

Need of a Rebate on Coal Exported in the Case of British Cargoes.—In case the export duty should be retained, there

* While these pages are passing through the press, a strike has broken out at the Westphalian mines, creating a demand for north country coal of England and Scotland, of which the proprietors and exporters of these districts will doubtless take full advantage.

† This was an exceptionally good year for trade.

‡ "Board of Trade Returns," 1904.

§ One, at least, of the witnesses, Mr. E. Wilson Taylor, General Manager of the Tredegar Iron and Coal Company, who objected to the export duty, stated that for revenue purposes he would prefer a uniform tax of (say) 2*d.* or 3*d.* per ton at the pit mouth all over the country in place of the export duty of 1*s.* "Evidence," January 19th, 1904.

is urgent need for a rebate of the duty on coal used for bunkering British ships at foreign stations. It was urged by Mr. E. C. P. Hull that it was never intended by Parliament that the incidence of the tax should fall upon British shipping. But this is just what happens when the tax is imposed on cargoes loading at British ports for the supply of coaling stations abroad. The case was very clearly put before the Commission by Mr. Hull, and was to the following effect:—*

When the export duty was imposed by by Sir Michael Hicks-Beach, as Chancellor of the Exchequer, he made it clear that his intention and expectation was that the duty would fall upon the foreign consumer; an expectation shared by his successor, Mr. Ritchie. It probably never occurred to either Minister that in so far as British coal is exported to coaling stations, and is there received as bunker supplies by British steamers, the tax is borne by the British shipowner, as distinct from the foreign. The quantity of British coal used at foreign and British ports abroad is about 5,000,000 tons annually, of which over one-half is used by British ships, that being the proportion of the British Mercantile Marine to that of the world. Therefore, about 2,500,000 tons used by British ships pays a tax which was never intended when it was imposed by Parliament; and on that quantity the exporter and merchant appears entitled to rebate of the amount, on certificates to that effect being produced at the Treasury.

* "Evidence," December 17th, 1903.

PART VII.

CHAPTER I.

AN INQUIRY INTO THE PHYSICAL LIMITS OF DEEP COAL-MINING.

THE reader will have observed that the limit of depth adopted in the estimates of the workable quantity of coal in the individual coal-fields and adjoining districts has been 4,000 feet, notwithstanding that there are hundreds of square miles stored with coal at greater depths than this, which have been estimated by the Royal Commissioners of 1871 to amount to no less than 48,486 millions of tons.* Now, it so happens that this limit of 4,000 feet, which I adopted in 1860 (on grounds stated in the first and second editions of this work), has also been adopted by the Commissioners both of 1871 and 1904 as approximately the greatest depth to which mining operations are likely to extend. This concurrence of views on a subject bearing so directly upon the question of the exhaustion of our coal-resources is gratifying to myself, and will probably be regarded by the public at large as a ground of confidence in the conclusions arrived at by both parties.

Down to the present time there are no coal workings at

* The quantity obtained by adding the amount of 7,342,000,000 tons included in the known coal-fields, to 41,144,000,000 tons in districts overspread by newer formations. "Report," vol. i, pp. 9 and 17.

depths exceeding 4,000 feet, though both in England and Belgium some mines approach this depth from the surface —as in the case of the "Produits Colliery" in the latter, and "Pendleton Colliery," near Manchester, in the former. It must be admitted, however, that the physical obstacles become serious at the above limit, and, as stated by Mr. John Bennett, an experienced mining engineer in the Somersetshire district, the effects of crush are greater in working seams at great, than in those of moderate, depths. But the evidence goes to show that no insuperable difficulties are likely to arise in connection with deep workings due to pressure. The chief obstacles to deep working are high temperature and cost. With regard to the question of cost: the larger expendituure rendered necessary for mines of great depth, will necessitate larger "takings" or areas, the employment of larger number of miners, improvements in ventilation, air passages of ampler dimensions, and increased use of electric light with compressed air as a motive power, by which the air of the mine, instead of being impoverished, will be enriched. To the above must be added mechanical appliances, such as coal-cutting machines for thin seams, and general adoption of the "long-wall" system. We shall now proceed to discuss the important subject of temperature at great depths.

That the temperature of the earth's crust increases as we descend, is a proposition which has been determined in the affirmative by observations extending over a large portion of the land-surface itself. It is, however, to be observed, that, compared to the radius of the earth, these observations extend only to a very small depth; nevertheless, they are perfectly sufficient for determining the problem, as far as it is calculated to influence the question of deep

mining, though not as regards the physical constitution of the interior of our globe. The following cases of special interest may be here stated.

Foreign Countries.—Numerous experiments with the object of determining the rate of increase of temperature have been made on the Continent—of which, however, only the results can here be given.

1. The temperature of the water of the Puits de Grenelle, near Paris, rising from a depth of 1,903 English feet, is 81·95° Fahr., giving a rate of increase of about 1° Fahr. for every 59·9 feet.*

2. At Mondorff, in the Grand Duchy of Luxemburg, there is an Artesian boring passing through several formations, which gave a result of 1° Fahr. for every 57 feet.

3. The Well at St. André, 50 miles west of Paris, gives a result of 1° Fahr. for every 56·4 feet.†

4. The Well of La Chapelle at Paris, at a depth of 600 metres, gives a result of 1° Fahr. for every 84 feet.‡

5. Boring at Sperenberg near Berlin, to a depth of 4,172 feet, nearly all in rock-salt, gave at a depth of 3,390 feet, a result of 1° Fahr. for 51·5 English feet.§

Monkwearmouth Colliery.—Professor Phillips, some years since, made observations on the temperature at this colliery, which have shown an increase of about 1° for every 60 feet.

Boldon Colliery near Newcastle-upon-Tyne.—Two sets of observations were made in dry bore-holes sunk from the floor of the colliery by Mr. M. Heckels, the Manager, in 1876, and gave the following results:—

* Prof. Everett, Brit. Assoc. Rep., 1871, p. 24.

† *Ibid.*

‡ *Ibid.*, Rep., 1873, p. 253.

§ Herr Dunker, quoted by Everett. *Ibid.*, Rep. 1876, p. 206. Other Continental cases will be found in these valuable Reports down to 1878.

Surface	... ...	48° Fahr.
Depth of 1,365 feet	... ...	75 ,,
,, 1,514 ,,	... ...	79 ,,

For the interval of 149 feet between the two holes we have an increase of 4° Fahr., which is at the rate of 1° Fahr. in 37 feet. For the whole depth of 1,514 feet we have an increase of 31° Fahr., which is at the rate of 1° Fahr. in 49 feet.*

Dukinfield Colliery.—The experiments carried out by Mr. Astley, during the progress of sinking the Dukinfield Colliery, are perhaps the most valuable of any hitherto undertaken in this country. Through the kindness of the late Dr. Fairbairn, of Manchester, I have been supplied with the whole of the details, which I here insert at length. The observations were conducted with great care. The thermometer was inserted in a dry bore-hole, and removed as far as possible from the influence of the air in the shaft, and left in its bed for a length of time, varying from half an hour to two hours. The results also carry with them more than usual importance, from the fact that they extend downwards to a depth of 2,055 feet, with an additional observation made in the open workings, at 120 yards from the shaft, and at a depth of 2,151 feet.

* Communicated by Mr. Lebour to Prof. Everett, Brit. Assoc. Rep. (1877), p. 197.

Thermometrical Observations in the Dukinfield Colliery Cheshire, between 1848 *and* 1859.*

Date.		Depth.	Temperature.	Description of Stratum.
1848.		Yards.	° F.	
July 28th ...	...	5·6	51	Red rock—no variation
1849.				
June	1st ...	231	57·7	Blue shale—wet
,,	12th ...	234·7	58	,, dry hole
,,	16th ...	237	58	,, ,,
July	14th ...	239	57·5	
,,	16th ...	240	58	,, ,,
,,	27th ...	242	57·5	,, ,,
August	9th ...	244	58	,, ,,
,,	25th ...	248	58	,, water
,,	27th ...	248	57·25	,, ,,
,,	31st ...	250	57·25	,, ,,
November	14th ...	252	58	
December	6th ...	256·5	58	Blue shale—dry
,,	15th ...	262·5	58·5	,, ,,
,,	22nd ...	270	58	Bituminous shale—dry
1850.				
January	9th ...	279	58·5	Strong warrant earth
,,	26th ...	286·5	59·12	Rock bands
February	11th ...	293	59·5	Coal roof
,,	19th ...	300	59·87	Warrant earth
March	5th ...	309	59·87	Purple mottled shale
1851.				
June	9th ...	358	62·5	Warrant earth
August	14th ...	373	64	Tender blue shale
November	7th ...	403	65	Coal roof
,,	19th ...	419	65·37	Rock bands

* These observations are published by Dr. Fairbairn, F.R.S., in the Report of the British Association for 1861.

Date.		Depth.	Temperature.	Description of Stratum.
1852.		Yards.	° F.	
February	6th ...	433	66·5	Black shale
May	28th ...	446	67	Strong fire-clay
1857.				
February	28th ...	483·5	67·25	Sandstone—dry hole
March	7th ...	487	67·76	Shale
April	11th ...	501	68·5	Sandstone
May	6th ...	511·5	68·75	Blue shale
,,	19th ...	521·5	69·38	Strong shale
June	9th ...	533	69·75	Warrant earth
,,	22nd ...	539	69·88	Blue shale
,,	27th ...	546	71·75	Coal and earth
July	18th ...	555	71·25	Grey sandstone
August	1st ...	563	72·25	Red rock (sandstone)
,,	15th ...	569	71·25	,, wet hole
September	2nd ...	578	72·12	,, ,,
,,	19th ...	589	71·5	,, ,,
October	3rd ...	597	72·25	Grey rock—dry hole
,,	17th ...	608	72·25	Coal roof—wet hole
,,	27th ...	613·5	72·25	Coal floor ,,
1858.				
March	22nd ...	621	72	Strong shale—dry
,,	29th ...	627	71·5	Dark-blue shale
April	23rd ...	645·5	72·25	Shale—dry hole
May	1st ...	651	72·25	,, ,,
,,	19th ...	658	72·5	,, ,,
June	9th ...	669	73·25	Bituminous shale—dry hole
,,	19th ...	673	74·12	Grey rock
July	17th ...	683	75·25	Blue shale
,,	21st ...	685	75·5	,,
1859.				
March	5th*... ...	717	75	"Black Mine" Coal roof
1880.				
June	.. ...	918	86·5	Cannel seam†

* In workings at 120 yards down engine incline from the shaft.

† The last observation gives a rate of increase of 1 degree for every 72 feet. (Thirteenth Report of Committee on Underground Temperature. Drawn up by Prof. Everett.) (Rep. Brit. Assoc., 1880.)

1. The first observation gives 51° as the invariable temperature throughout the year at a depth of 16½ feet.* Between 231 yards and 270 yards, the temperature was nearly uniform at 58°, and the increase from the surface would be at the rate of 1° Fahr. for 88 feet.

2. Between 270 and 309 yards, the increase was at the rate of 1° for 62·4 feet.

3. Between 309 and 419 yards, the increase was at the rate of 1° for 60 feet.

4. Between 419 and 613 yards, the increase was at the rate of 1° for 86·91 feet.

5. Between 613 and 685 yards, the increase was at the rate of 1° for 65·6 feet.

6. Between 685 and 918 yards, the increase was at the rate of 1° for 63·5 feet.

7. The observation No. 5 taken in the mine itself, at 120 yards from the pit, is valuable, as showing that the temperature of the air does not greatly differ from that of the surrounding strata.

The result of the whole series of observations (making allowance for the doubt regarding the first observation) gives an increase of about 1° for every 77 feet, which is a less rapid increase than that exhibited by the generality of experiments. But before discussing the cause of this abnormally slow rate of increase, I wish the reader to become acquainted with the experiments of not less interest and value made at another colliery near Wigan, and extending to a still greater depth, and in the same parallel of latitude.

* This observation for the position of the invariable stratum is probably not reliable. The depth ought to be greater, but its accurate determination

Rose Bridge Colliery, Wigan.—The following observations on the temperature of the strata during the progress of sinking the pits of Rose Bridge Colliery, at Ince, near Wigan, then the deepest mine in Britain, were communicated to the author by Mr. Bryham, the Manager, by whom they were carried out. They differ materially from those of Dukinfield just described.*

Thermometrical Observations at Rose Bridge Colliery.

Date.	Depth.	Strata.	Temperature in open pit.	Temperature in solid strata.
	Yards.		Deg. Fahr.	Deg. Fahr.
July, 1854	161	Blue shale... ...	—	64·5
August, 1854	188	Warrant earth ...	—	66
May, 1858	550	Blue shale... ...	—	78
July, 1858	600	Warrant earth ...	—	80
May 18th, 1868 ...	630	"Raven" coal ...	73	83
July 24th, 1868	665	Strong shale ...	75	85
April 19th, 1869 ...	673	"Yard Coal" mine	76	86
November 18th, 1869...	700	Strong blue metal...	76	87
February 22nd, 1869 ...	736	,,	76	88½
March 12th, 1869 ...	748	Shale	77	89
April 17th, 1869 ...	762	Linn and wool, or strong shale ...	78	90·5
May 3rd, 1869 ...	774	Strong shale ...	80	91·5
May 19th, 1869 ...	782	Blue metal ...	79	92
July 8th, 1869... ...	801	Strong blue shale...	79	93
July 16th, 1869 ...	808	Coal (Arley mine)	79	93½

Assuming the surface temperature to be 49°, we have on the whole depth of 808 yards, or 2,424 feet, an increase of

requires a series of observations which could not well have been made in the present instance.

* These observations, with a complete section of the strata to a depth of 815 yards from the surface, are given in the "Third Report of the Committee on Underground Temperature," Rep. Brit. Assoc., 1870.

44·5°, which is at the rate of ·0184 of a degree per foot, or 1 degree for every 54·4 feet, as against 1 degree for about every 77 feet at Dukinfield.

Cause of Difference in Rate of Increase.—With strata so nearly similar, and in two neighbouring counties, we should scarcely have expected so much difference in the mean rates of increase downwards. In this respect, Rose Bridge agrees nearly with the average results obtained elsewhere; Dukinfield far surpasses all other deep mines or wells, so far as our present records extend, in slowness of increase.*

In a paper published in the Proceedings of the Royal Society of London,† I have endeavoured to show that the cause of the discrepancy in the results obtained at the two localities is due to the differences in the position of the strata in each case. At Rose Bridge the beds are nearly horizontal, at Dukinfield they are inclined at an angle varying from 30 to 35 degrees, rising and cropping out to the eastward. Now, strata of various kinds, such as alternating sandstones, shales, clays, and coal, with different conducting powers, must offer more resistance to the transmission of heat in a direction across, than parallel to, their planes of bedding; for Mr. Hopkins has shown, that every sudden change of material is equivalent to an increase of resistance; and it is obvious that highly-inclined strata, such as those at Dukinfield, furnish a path by which internal heat can travel obliquely upwards and outwards, without being frequently interrupted by these breaches of continuity. On the other hand, deep-seated horizontal strata, like those of Rose Bridge, offer a succession of resisting surfaces to the upward passage of internal heat.

* "Rep. Brit. Assoc.," 1870, p. 32.

† "Proc. Royal Society," 1870, vol. xviii, p. 175.

As, therefore, the rate of increase of temperature is inversely proportional to the upward flow of the heat, we have here a solution of the results arrived at in the cases before us. To this it may be added, that inclined strata furnish great facilities for the convection of heat by the flow of water along the planes of junction.

The general inference which may be drawn from the cases just described, as far as they bear upon the temperature of coal-mines, is this: that in those districts where the strata are highly inclined (at angles varying from 30 to 60 degrees), the underground temperature will be lower than in the case of those where the strata are in a position approaching the horizontal.

Mean Result.—The illustrations already adduced will probably be considered sufficient to show that the increase of temperature is a reality, which becomes a sensible obstacle at a slightly variable depth; and will have to be encountered and overcome by artificial means when the depth exceeds (say) 1000 yards. On this point the Commissioners on Coal-resources for 1871, have arrived at the conclusion that at a depth of 1,000 yards (3,000 feet) the temperature of the earth would amount to 98°. Under "the long-wall system" of working, a difference of about 7° appears to exist between the temperature of the air and that of the working faces, and this difference represents a further depth of 420 feet; so that the depth at which the temperature of the air would, under the present conditions, become equal to the heat of the blood, would be about 3,420 feet. Beyond this point the considerations affecting increase of depth become so speculative that the Commissioners leave them in uncertainty; but they consider it may be fairly assumed that a depth of at least 4,000 feet may ultimately be reached in coal-mining.

As regards the views of the Commission of 1904, Professor Dixon considers that it seems certain that the temperature could not be sufficiently cooled at depths exceeding 4,000 feet without some special appliances or arrangements, in addition to the ordinary methods of ventilation, so as to allow of working with safety to health.

In reviewing the evidence laid before them by several gentlemen of experience, the Commissioners have come to the conclusion that the rate of increase may, for ordinary cases, be assumed to be 1° F. for every 60 feet. From this mean result there will be variations, as in the case of Dukinfield and Rose Bridge; one of which gives a less rapid, the other a more rapid, rate of increase. Assuming, however, the rate as above stated, it is necessary to determine the temperature to which the addition of 1° for 60 feet is to be made, in order to calculate the temperature at different depths; in other words, the position of the "*invariable stratum*."

Now, it has been found that at a certain depth, varying from 30 to 50 feet, the temperature remains the same all the year round; and is nearly that of the mean annual temperature of the locality. The depth of this "invariable stratum," according to Humboldt, depends upon the latitude of the place (increasing from the equator towards the poles), on the conducting power of the rock, and on the amount of difference between the temperatures of the hottest and coldest seasons. At Greenwich, the mean temperature is 49·5°; and in the deepest of several underground thermometers, 25 feet from the surface, the extreme variations were (1858) from 48·85° to 52·27°, giving a mean of 50·56°—a result, differing by only

half a degree from that of Dukinfield Colliery, obtained ten years earlier.*

We may, therefore, adopt 50·5° as the standard of departure—or, in other words, the *temperature of no variation* at a depth of about 50 feet underground.

But there is an additional element tending to raise the heat in deep mines; namely, the increased density of the air. The effect of this will be greatest when the air is stagnant; but when there is a rapid circulation of the air-current it will probably be small, and may be disregarded.†

Pendleton Colliery, Manchester.—One of the most important cases for determining the temperature at great depths is that afforded by the workings in the "Rams Mine" in Pendleton Colliery, of which the details were furnished by Mr. H. Bramall, manager of this important colliery ‡

The coal is worked by a shaft descending to a depth of 1,545 feet, from the bottom of which "down brow" tunnels are driven on the dip of the coal, from which levels are cut into the coal at successive intervals to an ultimate depth of 3,483 feet from the surface. A special examination of the temperature of the mine was made on March 12th, 1902, the surface temperature being 48° F.,

* "Greenwich Observations" for 1858.

† This element has not been noticed by the Commissioners of 1871, though I drew attention to it in the 2nd edition of this work. From this I infer that the Commissioners did not consider the increased density of the air in a well-ventilated mine as calculated materially to increase the temperature.

‡ Evidence, July, 1902. Diagram in supplement to the 1st Rep., Plates 1 to 7 (1903). Pendleton Colliery was commenced in 1838 by Mr. Fitzgerald; and was inundated by a flood of water in 1843, of which an interesting account is given by Prof. Galloway, "Annals," 2nd ser., p. 17.

and that of the pit bottom, 65°. The results are given in the following table :—

Temperatures of Air and Strata in the Rams Mine at Pendleton Colliery, July, 1902. The Temperatures of Strata were taken in holes bored in the floor of the Mine, 3 feet 6 inches deep.

Place.	Depth below Surface.	Temperature of Air.	Temperature of Strata.
	Feet.	° F.	° F.
Surface...	—	64·0	—
In shaft...	27	—	63·0
,, ...	780	—	66·0
Shaft bottom	1,545	73·5	68·5
No. 1 level	1,716	74·5	71·5
,, 2 ,, ...	1,896	74·75	72·5
,, 4 ,, ...	2,154	75·75	76·5
,, 6 ,, ...	2,508	76·75	75·0
,, 8 ,, ...	2,748	77·5	77·0
,, 10 ,, ...	2,958	78·5	80·75
,, 11 ,, ...	3,108	79·5	81·75
,, 12 E., far end	3,180	93·75	97·0
,, 12 W.	3,219	80·5	87·5
,, 13 W.	3,300	82·0	91·5
,, 13 W., bottom of brow ...	3,400	84·25	96·5
,, 13 W., far end	3,219	93·75	102·5
,, 13 E.	3,300	83·75	89·5
,, 13 E., bottom of brow ...	3,483	92·5	100·0

Another series of observations was made at Agecroft Colliery in the same neighbourhood, on July, 1902, descending to a depth of 2,940 feet, and showing a temperature of 84° F. in the air, and of 92·5° in the strata ; but as the Pendleton Colliery descends to a much greater depth, the results are of more value and interest, and are here given in detail. And at Wigan, according to the

statement of Mr. J. Higson, the Arley Mine is being worked at a depth of 730 yards (2,190 feet), and the temperature of the air at the face was found to be about 90° F.; that of the surface being 61° F.*

The following table gives the maximum temperature at the various depths according to the average rate of 1° F. for 60 feet :—

Table showing Theoretical Increase of Temperature.

Depth.	Increase of Temperature due to depth.	Depth.	Increase of Temperature due to depth.
Feet.	° F.	Feet.	° F.
1,000	63·0	2,750	95·5
1,500	73·8	3,000	99·6
1,750	78·8	3,250	103·8
2,000	82·0	3,500	108·0
2,250	87·1	3,750	112·1
2,500	91·3	4,000	116·3

From the above table it will be observed, that at a depth of 3,000 feet the temperature of the strata exceeds that of blood heat, and that were it not for the effects of ventilation in reducing the temperature, the limits of coal-mining would be circumscribed within this depth.

Ventilation.—To effective ventilation, however, we must look for ability to win those seams which lie within the additional thousand feet of strata; and, as to what extent this is likely to be accomplished, we have already some valuable evidence. In reference to the effect of the heated

* Evidence of Mr. John Higson, Roy. Coal-Commission, November 25th, 1902.

walls of the rock on the ventilating air-current, the Commissioners remark as follows:*—When cool air enters a heated mine it absorbs heat from the surfaces of the passages through which it flows, and the rate of this absorption somewhat exceeds the ratio of the difference between the temperature of the air and that of the surrounding surface with which it is in contact. By the absorption which thus takes place the air is heated, and this heating process is most rapid at first, when the difference of temperature is greatest, and gradually diminishes as the length of the passage is extended; never ceasing until complete assimilation of the temperature is effected. The progress towards assimilation is more rapid when the air comes in contact with the working face of the coal, which, from being newly exposed, is more highly heated than the surfaces of the permanent air courses. The rapidity, however, with which the air takes up the heat from the working face depends in a great degree upon the system of working. In the cellular system, called "pillar and stall," the air seems to acquire, almost immediately, the full temperature of the coal; but under the "long-wall" system there are instances of the air retaining a considerable inferiority of temperature after sweeping past the working face.

The views of Prof. Redmayne, as stated at the meeting of the South Staffordshire Institute of Mining Engineers, on working coal at great depths, both for winding, cutting and ventilating, should receive attention, as he advocates the more general adoption of compressed air driven by electric motors. The following is an extract from his address, as reported in the *Colliery Guardian* (October 21, 1904):—

* Report, vol. i, p. 82 (1871) (Committee A, of which Sir W. C. Armstrong, C.B., was Chairman).

"That part of the problem which related to mechanical appliances did not, he thought, present any insuperable obstacles, for the difficulties in the way of winding from great depths, at least in so far as concerned depths down to 5,000 feet, had been satisfactorily solved, without resorting to the use of tapered ropes or stage winding. The Whiting system of hoist seemed to meet requirements up to this depth at the Red Jacket (vertical) shaft at the Calumet and Hecla Mine in Northern Michigan, U.S.A., and he was of the same opinion as Mr. Hennen Jennings, that with the adoption of the tail rope in connection with that system, its usefulness would be much increased. Nor did he think we need be greatly concerned as to the difficulties in the way of the cheap and effective transmission of power to great depth or great distances underground. For though in "fiery" coal-seams it might be most dangerous—injudicious, at any rate—to use electrically-actuated coal-cutters, there should be no objection to working air compressed by electric motors stationed some considerable distance along the main intakes, and conducting the compressed air to the face. 'Secondary' haulage could be similarly worked."

Effects of the Seasons.—It might have been supposed that the influence of the comparatively colder air of winter and warmer air of summer would be felt throughout the workings of a coal-mine, but the Commissioners have come to a different conclusion, upon the evidence offered them on this subject. All the witnesses examined agreed in stating that summer and winter make no difference in the temperature of the air in mines, except at short distances from the shaft. This is due to the fact, that great disparity of temperature is rapidly reduced when the

air comes in contact with the air passages: thus, very cold air upon entering the mine rapidly absorbs the heat of the strata, and the greater the difference of temperature the more rapid is the absorption. I am, therefore, induced to abandon an opinion which I formerly held, that air at a low winter temperature might be, in some cases, rendered available for mines which in the summer months might become unworkable.

Effect of the increased circulation of Air-current.—On this subject the evidence offered chiefly by Sir Lindsay Wood, of Hetton Hall; Mr. J. J. Atkinson, of Chilton Moor; and Mr. John Knowles, of Pendlebury, has tended to show that little change of temperature is effected by increasing the circulation of the air in the passages of the mine. From the tabulated statement given in the report, it appears that in one case observed at Hetton Collieries, when the distance from the shaft was from 2,296 to 2,925 yards, the difference between temperature of the strata and of the air was only 2°, while the volume of air in circulation was 22,400 cubic feet in one case, and 11,400 in another.

Sir Lindsay Wood has shown by a table the gradual approximation of the temperature of the air to that of the strata through a distance of 3,422 yards; and he found that at that distance no perceptible difference took place in the temperature of the current when reduced from 41,800 cubic feet to 3,000 per minute.

Effect of Humidity or Dryness of the Air.—The question of the maximum temperature of air which is compatible with healthful labour is an exceedingly difficult one to determine, and the Commissioners had evidence laid before them showing that in some cases human labour had been

carried on at temperatures as high as 180° F.; but it was observed, that in these cases the thermometer indicated radiant heat, and not that of the surrounding air. Upon one question, however, the witnesses were unanimous: that a high temperature was endurable very much in proportion to the dryness of the air; while on the other hand where it was saturated with moisture, the same degree of temperature became intolerable.

Now, it is a matter of general observation, that in deep mines the air is comparatively dry. The water, which is generally present, often in large quantities in shallow mines, gradually lessens in quantity as we descend, and at depths of 500 or 600 yards ceases altogether. The air, therefore which circulates through the passages of deep mines, gradually parts with its moisture while it rises in temperature, and passes into a state agreeable to the human system, and conducive to health. The hygrometric condition of the air in deep mines may, therefore, be regarded as in some measure tending to counterbalance the effects of a high temperature, and to render possible healthful labour at great depths from the surface.

The following tables of observations on this subject are of much interest, and are extracted from the Report of the Royal Commissioners (1871):—

No. 1.—SUMMARY OF HYGROMETRIC OBSERVATIONS IN COAL MINES IN LANCASHIRE, NORTH WALES, CHESHIRE, STAFFORDSHIRE, AND YORKSHIRE.

Name of Mine.	Place of Observation.	Depth.	Distance from Downcast Shaft.	Dry Bulb.	Wet Bulb.	Relative Humidity, 100° being Saturation.
		Feet.	Yards.	°	°	°
Rose Bridge Colliery ...	End face of a level	2,391	69	71·0	64·5	68·3
	Do.	2,391	103	72·5	65·5	66·8
	Do.	2,391	303	75·0	68·0	68·1
Pendleton Colliery ...	A working face ...	2,064	1,747	81·0	73·0	66·5
	Do. ...	2,214	727	77·0	69·0	64·8
Astley Pit, Dukinfield Colliery ...	Do. ...	2,216	590	73·0	69·0	80·7
Astley and Tylesdale Colliery ...	Face of level ...	1,200	2,035	69·0	69·0	100·0
Bank Colliery	A working face ...	900	120	68·0	67·0	94·7
Low Side Colliery	Do. ...	492	586	60·0	60·0	100·0
Anderton Hall Colliery	Face of level ...	900	600	63·0	62·0	94·3
Bradleyfold Colliery	A working face ...	540	1,520	70·0	69·0	94·8
Wynnstay Colliery, North Wales	Do. ...	1,173	611	67·0	66·0	94·6
Hafod Colliery, North Wales	Do. ...	1,815	195	75·0	73·0	90·4
	Do. ...	1,452	390	72·0	70·0	90·0
Clifton Hall Colliery	Do. ...	1,640	1,262	69·0	63·0	70·0

Remarks.—In the Tables from which this Summary is compiled the depth is stated in yards, and the distance travelled by the air computed from the mouth of the shaft. To facilitate comparison with the Durham observations, the depth is here expressed in feet, and the distance travelled is taken from the bottom of the shaft.

Working at a Great Depth.

No. 2.—Translation of a Report supplied by the Belgium Government.

The deepest coal-mines are the following :—

Name of Mine.	——	Depth.	
		Metres.	Feet.
1. Charbonnage du Poirier at Montigny-sur-Sambre	Pit St. Andre...	940	3,083
2. Charbonnage de Marcinelle-Nord, at Marcinelle	Pit No. 11 ...	986	3,234
3. Charbonnages Réunis de l'Agrappe, at Frameries...	Pit No. 10 ...	1,000	3,281
4. Charbonnage de Marchienne, at Marchienne	Pit No. 1 ...	1,025	3,363
5. Charbonnage des Produits, at Flenu...	Pit No. 18 ...	1,150	3,773

Most of the questions upon which the Commission of Coal Supplies invited information are treated in the Memoranda of Mons. M. S. Stassart, "Conditions d'exploitation à grande profondeur en Belgique" (published by the International Congress of Mining and Metallurgy, Paris, 1900). In this work very exact details are found concerning the temperatures and the winding machinery.

In what follows the mines will be indicated by the number in order to save space.

(*a*) Temperature in the working place, its effect upon the number of hours of work and ventilation. The principal facts upon these points are brought together in the following tables :—

TABLE 3.

Mines.	Depth in Metres and Feet.	Total Quantity of Air in the Fan Drift in Cubic Metres and Feet.	I. Total Quantity at the Bottom in Cubic Metres and Feet.	Mean Quantity.		
				Per Workman at the Face in Litres.	Per Workman under Ground in Litres.	Per 100 tons Extracted.
No. 1	940 (3,083 ft.)	—	—	—	—	—
No. 2	986 (3,234 ft.)	50 (1,750 c. ft.)	35 (1,225 c. ft.)	280 (9·8 c. ft.)	109 (3·9 c. ft.)	7·300 (255·5 c. ft.)
No. 3	1,000 (3,281 ft.)	38 (1,330 c. ft.)	25 (875 c. ft.)	424 (14·9 c. ft.)	123 (4·3 c. ft.)	14·400 (504 c. ft.)
No. 4	1,025 (3,363 ft.)	40 (1,400 c. ft.)	28 (980 c. ft.)	209 (7·3 c. ft.)	70 (2·5 c. ft.)	4·000 (140 c. ft.)
No. 5	1,150 (3,773 ft.)	33 (1,155 c. ft.)	21 (735 c. ft.)	809 (28·3 c. ft.)	269 (9·4 c. ft.)	19·009 (665·3 c. ft.)

TABLE 4.

Mines	1	2	3	4	5
Temperature of the working place	25 to 29° C. (77 to 84·2° F.)	22 to 28° C. (71·3 to 82·4° F.)	29 to 32° C. (84·2 to 89·6° F.)	28° C. (82·4° F.)	25 to 36° C. (77 to 96·8° F.)
Temperature at the surface	3° C. (37·4° F.)	4° C. (39·2° F.)	5° C. (41·8° F.)	7° C. (44·6° F.)	2° C. (35·6 F.)
Volume of air in the working place	0·616 c. m. (21·6 c. ft.)	2·102 c. m. (73·6 c. ft.)	2·708 c. m. (94·8 c. ft.)	2·53 c. m. (88·6 c. ft.)	3·38 c. m. (118·3 c. ft.)
Velocity of air current	0·40 m. (1·3 ft.) per sec.	— — —	2·22 m. (7·4 ft.) per sec.	1·44 m. (4′ 9″) per sec.	1·78 m. (5′ 10″) per sec.

Only way to Reduce Temperature at Great Depths.

The only practical method of reducing the temperature sufficiently in the working places at a great depth consists in making large volumes of air circulate through them At the Marcinelle Colliery it has been attempted to cool down the working place below the 986 metres (3,234 feet) horizon by means of water. The results have been inconclusive and the system given up. The use of water upon the shale at a high temperature causes it to swell, and leads to a considerable expense for keeping the roadways in order ; besides the moisture renders the work uncomfortable in atmospheres of high temperatures. The work at the working face is not disagreeable at a temperature of 30° C. (86° F.), provided that the air current has a velocity of 1½ (4 feet 9 inches) to 2 metres (6 feet 6 inches) per second. It is easier to work with velocities of 2⅓ metres (8 feet 3 inches) and the atmosphere at 38° C. (100° F.) than in weak currents with a temperature of 30° C. (86° F.). This is easily explained by the refreshing feeling due to the evaporation of the perspiration of the workmen. At the Produit Colliery the workmen are at work for 10 hours without being greatly inconvenienced. It must be remarked that the proportion of workmen who are ill is no greater at Pit No. 18 than at the pits of average depth.

Effects of Pressure.—It is impossible to speak with certainty of the effect of the accumulative weight of 3,000 or 4,000 feet of strata on mining operations. In all probability, one effect would be to increase the density of the coal itself, and of its accompanying strata, and so to increase the difficulty of excavating. Coal-mining labours

under a disadvantage not felt in mining other minerals, namely, the impossibility in general of having recourse to blasting. The increased firmness of the strata will most assuredly be felt at great depths; but the question whether the resistance will prove beyond the powers of manual skill and mechanical contrivances to surmount, can only be solved by actual experience. I was informed by Mr. Bryham, that, from his experience, the density of coal-seams is not perceptibly greater at 500 or 600 yards than at half that depth; at the same time, in Dukinfield Colliery, where the Black Mine was formerly worked at a depth of about 2,500 feet, the pressure was so powerful as to crush in circular arches of brick 4 feet in thickness, and in one case, a pillar of cast iron 12 inches square, supporting a roof of only 7 feet in extent, was snapped in twain !*

In the face of these two obstacles—temperature and pressure, ever increasing with the depth—I have considered it utopian to include in calculations having reference to coal-supply, any quantity, however considerable, which lies at a much greater depth than 4,000 feet, unless it consists of seams of the best quality and good thickness. Under these conditions most of the witnesses consider that coal may be worked to depths of about 5,000 feet with the aid of coal-cutting machinery and improved appliances for ventilation.

Minimum Thickness of Workable Seams.—This was one of the questions on which the decision of the Commission of 1904 was sought, and on which it cannot be said that any definite decision has been arrived at, and the reason is obvious. In the first place, the limit of 12 inches was

* As I was informed by Mr. Seddon, the underlooker.

adopted in accordance with the decision of the Commission of 1871, and for purposes of comparison. Seams of 12 to 18 inches in thickness have doubtless been, and are being, worked in hilly districts by adits from the outcrop, or in shallow pits, where thicker seams are either absent, or where high prices rule; but we have no experience of working such seams at depths of 2,000 feet and upwards, and it must be left to individual judgment to form an opinion regarding the possibility of working such seams at a profit between (say) 2,000 and 4,000 feet. As the miner cannot exist under a roof less than 4 or 5 feet above the floor, it is necessary to excavate some 2 or 3 feet of strata in order to give him headway, and as this material is generally useless for purposes of commerce, its exploitation is so much dead loss. Again, the production of coal per man is less in thin seams than in thick, that is seams ranging in thickness from 3 to 6 feet or more. On the other hand where a thin seam is associated with iron-stone or fire-clay, both may be worked together with advantage. Coal cutting by machinery also facilitates the exploitation of very thin seams; and when the thicker beds have been worked out from a pair of shafts still in existence, it may be found of advantage to open out on seams which had previously been neglected owing to insufficient thickness. But all these prospective conditions notwithstanding, they will scarcely apply to mining operations at depths of over 2,000 feet; and in endeavouring to arrive at estimates of quantities of coal for future use, and at great depths, it seems desirable to eliminate the quantities (often very large in the aggregate) credited to coal seams below approximately 2 feet in thickness.*

* On this subject the reader is referred to the views of Herr Nasse on the

In truth, the quantities so credited constitute but a small proportion of the totals, as appears from the estimates of the Commissioners. Taking the quantities between 12 and 18 inches, the percentages range from about 0·57 in the Midlands to 8·8 in Scotland, as will be seen by the following cases selected from the returns from several districts :—

Percentages of Quantities of Available Coal from Seams Ranging from 12 *to* 18 *Inches in Several Districts.*

	Per cent.
1. Cumberland	1·77
2. Midlands	2·8
3. Lancashire, Cheshire, and N. Wales ...	5·68
4. Northumberland	6·53
5. Durham	7·96
6. Yorks, Derby, and Notts	5·2
7. South Wales	9·5
8. Scotland	17·6

The result being approximately 7·5 per cent. for the whole; quite an inappreciable amount, yet, in the author's opinion, giving by elimination a closer estimate of available coal than one which would include the quantities from the seams above referred to. Personally I should prefer a deduction of 10 per cent., so as to include seams between 18 and 24 inches, but there is reason to believe that considerable deductions have been made by the District Commissioners themselves in their estimates, in order to meet the objections here dealt with.

Waste or Loss in Working.—This is a subject on which a large amount of important evidence was given by witnesses from the mining districts, but which can only be

experiences and results of attempting to work thin seams of coal at great depths in the Belgian and German Colonies; ch. iv, p. 458.

summarised here. It may be stated that there has been in nearly all districts a great improvement in recent years in the utilisation of small coal, and in the working of good seams on the "long-wall" system, there is practically no waste in working allowed. There are some districts, such as that of South Staffordshire, where, owing to the extraordinary thickness of one or more seams, together with proximity to the surface, great loss of coal has been occasioned by rude ways of mining in early times and flooding by surface water, but such cases are exceptional, and when they occur are being specially dealt with. Cases where in former times it was considered necessary to leave double barriers of solid coal between two adjoining properties are now being restricted to one barrier, by mutual arrangement; and where, in former times, large blocks of coal were left for the support of buildings, railways, and canals, it has been found possible, owing to increase of depth, to extract the coal, the surface being levelled up as it subsided.

Notwithstanding, however, all attempts to recover this mineral, large deductions have to be made in estimating the resources for future years. Thus, in North Staffordshire, the deductions made on seams considered to be available under 4,000 feet in depth amount to 17 per cent. for all causes; in South Staffordshire the amount is 27·5 per cent.; in Northumberland, 22·6 per cent.; and in Lancashire, 20·7 per cent.; the above causes consisting of barriers left for buildings, etc., and "faults" or natural obstacles. Thus we may conclude that about one-fifth of all the coal left unworked is irrecoverable, owing to obstacles both natural and artificial, partly owing to mining operations in a highly civilised and populous country, such as is the case with the British Isles.

CHAPTER II.

DURATION OF OUR COAL-SUPPLY.

As this question is included in the "Terms of Reference" of the Commission for 1904, it was dealt with by the Commissioners in their final report, but with extreme brevity. As they very properly state, it turns chiefly upon the maintenance, or the variation, of our annual output of coal. If we assume that our present annual output of about 230 million tons were to be maintained, the available resources would last for over 600 years, and the period might be somewhat increased by including some amount of coal below 4,000 feet in depth.* On the other hand, should the demands on our coal reserves be increased, the period of duration would be proportionately diminished.

In order to ascertain the views of persons actually engaged in coal-mining, throughout the country, regarding the prospects of future production in their respective districts, questions were addressed to them by the Com-

* The problem works out in this way :—

	Millions of tons.
1. Quantity of reserve coal in the visible coal-fields and borders	100,867
2. Quantity in the concealed and unproved coal-fields	38,986
Total	139,853

The above divided by 230 millions of tons, the present output, gives 600 years; all the above are in "round numbers."

missioners, inviting them to state their views regarding the prospects of an increase, or otherwise, of output in the near future. Making allowance for variations of opinion, depending on the special conditions of the districts, the general result seemed to be that, as regards the larger coal-fields, the present output could be maintained, and somewhat increased for a period of about 20 or 25 years, after which a gradual diminution might be expected; in other words, that the maximum production of coal would be reached. This view was not to be regarded as mere guess work, but was grounded on the inference that within the period referred to a large number of collieries would necessarily be "worked out," and consequently closed, and also, that the better, and thicker, seams of coal would be exhausted within moderate depths of the surface. Under these circumstances, coal-mining, in the future, would be carried on under less favourable conditions than at present. Collieries involving the outlay of moderate capital and working seams at no great depth, would give place to others where very large outlay would be required, owing to increase of depth and proportionately more powerful machinery and expensive plant. The areas of leases would be larger than at present, and, consequently, much coal would have to lie dormant in the earth for reserves; wages would probably have risen, tending to restrict the use of mineral fuel for all purposes; and, unquestionably, the use of electricity would replace that of steam for all purposes of mining. This last point is one of very great interest and importance, on which I wish to enlarge somewhat. This marvellous and far-reaching agent in the distribution of power is even now making itself felt in every direction. It is being used for locomotion and traction, for driving machinery, for

lighting, and even for navigation; it is also becoming an important agent in coal-mining in this country, but to a far larger extent on the continent, as appears from a statement read before the Manchester Geological and Mining Society, by Mr. Maurice Georgi.* As far as the author is aware, although electricity has not yet been applied in Great Britain for winding coal, though it is used for lighting mines, and under-cutting coal-seams, it is being introduced for all purposes connected with colliery working on the continent. Mr. Georgi says "that nearly all the principal mines in Germany, Belgium and France, are being equipped electrically throughout, as far as their means will allow. As regards British Collieries, in the year 1902, the number of machines, all worked principally for coal-cutting by electricity, was 149, and in the year following they had increased to 231; in a greater number of cases compressed air was employed;† so that this latter mode of employing power was more in favour than the former. Nevertheless, coal remains in this country the chief source of electrical energy; water power, depending on gravitation, being so limited in its application as to be a negligible quantity, as I have endeavoured to show in a previous page (p. 387).

But returning from this digression to the question of the duration of our coal-reserves, it will be clear, on reflection, that the actual exhaustion of our coal-fields must be a process very gradual and far distant. The general output will reach a maximum which may possibly be arrived at within a quarter of a century, and then will ensue a decline still more gradual. As was the case with the origin of

* 'Trans. Manch. Geol. Soc. and Mining Soc.,' vol. xxvii, p. 455.

† Viz.: 334 in 1902, and 412 in 1903.

coal-mining, so we may suppose will be its decline. From the 14th century, when the mining and use of coal began to take form as a part of the settled trade of the country, especially around Newcastle-on-Tyne,* down to the present day there has been a gradual though variable increase in the output; and in a similar manner the descent from the maximum to the close will be represented by a downward curve, by no means uniform, and probably much more prolonged than that on the ascending side of the apex.†

The Export Duty on Coal.—It is a matter for regret that the subject of the export duty of 1*s.* per ton on coal of the value of 6*s.* per ton and upwards was remitted to the consideration and report of the Members of the Royal Commission of 1904. The question arose under the clause in the Terms of Reference "whether the mining industry, under present conditions, is maintaining its competitive power with the coal-fields of foreign countries." But there are other clauses necessarily involving a consideration of the export duty, such as the consideration of "the effect of our exports of coal on the home supply," and it should be remembered that Mr. Ritchie, when Chancellor of the Exchequer, in replying to a deputation which waited upon him regarding this very question, referred to the Commission as likely to afford evidence of the effect of the export duty on the coal trade of the country.‡ It was, therefore, obligatory on the Commissioners to report on the question.

* R. L. Galloway, 'Proc. Soc. Antiq., Ap.,' 1879.

† On the subject of the history of coal-mining the reader will find some interesting information in the 4th edition of this book, chap. i.

‡ Speech, June 23rd, 1903. In this speech the Chancellor very clearly pointed out the difficulty of assenting to a reduction or repeal of the coal tax the face of the growing prosperity of the export trade.

I have already, in a previous page, dealt shortly with this subject, but, considering its interest and importance, a few further observations may not be considered out of place.

Evidence from witnesses representing coal owners and ship owners was given in a sense adverse to the continuance of the tax, as putting upon them a burden, when in competition with foreign countries, especially Germany, which has recently made great efforts to secure markets once almost exclusively in British hands. It was represented that we were losing some ports in northern Europe formerly open to our trade; and that the shilling duty just made the difference between the price of coal shipped from British collieries and that coming from Westphalia and other mining centres. These gloomy anticipations, however, did not appear to be sustained when brought to the test of returns of output and shipment of coal from British sources of supply. It was found that, instead of a decrease of trade the export of coal had been steadily increasing since 1901, the year in which the tax came into operation.

The previous year, 1900, was admittedly one of exceptional prosperity, when the output of our coal-fields reached more than 225 millions of tons and the export of coal amounted to over 44 millions. The "boom" of that year was inevitably succeeded by a fall; so that in 1901 the total output was reduced by about 5 millions of tons, and with it there was also a fall in the export to the extent of 622,011 tons. But in the two succeeding years of 1902—3 there has been a material increase, which we now know has been maintained in the present year (1904), the figures being:—

		Tons.
Export of coal,	1901	41,877,081
,,	1902	43,159,046
,,	1903	44,950,057
,,	1904	46,256,547

there being an increase of 1,305,490 tons in 1904 over the preceding year.*

From the above figures it will be seen that notwithstanding the export duty, there has been a large increase in the quantity of coal exported from our harbours to foreign countries.

When we come to look into the reports of export trade in coal from those coal-fields which are the chief producers for foreign countries, a similar result meets our view. The chief of these districts are Scotland, the Northern district, including Northumberland and Durham, the North Midland, including Yorkshire, Derbyshire, and Notts, Lancashire and Cheshire and South Wales, we find in every case an increase of output for the year 1903, as compared with the preceding year, 1902, as will be seen from the following returns:—†

Output of Coal from Exporting Districts.

	Tons.
Increase of 1903 over 1902—	
Scotland	876,931
Northern	1,467,096
North Midland	239,943
Lancashire and Cheshire	74,163
South Wales and Monmouthshire	848,608

* This does not include coal for bunkerage, which amounted to 17,190,900 tons.

† Report and Statistics issued by the Home Office in 1904.

From the above it will be clear that the export duty has not had the effect of reducing the output of these districts.*

During the period referred to the low freights of shipping have doubtless been favourable to a large export, and these have been taken advantage of by the exporters; nor can it be denied that the tendency of the export duty is to curtail the quantity shipped. In other words, we should all be pleased if the revenue was in so flourishing a condition that the Chancellor of the Exchequer could dispense with this, or any other, tax tending to impede trade. But few of us outside the owners of collieries and ships would like to see the coal tax repealed, in order that the income-tax which weighs oppressively on the whole tax-paying community, might be increased; a result which appears inevitable if such a measure as the repeal of the export duty were adopted.

There was one point, however, on which the Members of the Commission appeared unanimous, namely, that with the existing large reserves of coal in the ground, as determined by the Commissioners, there is no necessity *at present* for imposing a tax in order to conserve for home use the unworked mineral fuel below the surface; and this applies even to our most valued of mineral assets, the Welsh steam coal. The quantity of this rare and important mineral, as determined by Sir W. T. Lewis and his assistants, has been given in another page,† from which it will be seen that the supply is abundant for a good number of years to come. The day may arrive within the present century when exclusive action of the kind referred to may become a matter of policy, but it does not seem necessary to be resorted to at the present time.

* The returns for 1904 from these districts have not yet come to hand.

† P. 402.

PART VIII.

CHAPTER I.

PHYSICAL GEOLOGY OF THE CARBONIFEROUS ROCKS.

South-Easterly Attenuation of the Coal-Measures of the North of England.—The investigation into the original manner of distribution of the Carboniferous Rocks is one of much interest to the physical geologist, while it also possesses a certain economic importance. The exact information which the extension of the Geological Surveys over the centre and north of England has afforded, enables us to arrive at definite conclusions on this subject.

Having on former occasions gone very fully into the details,* I shall here content myself with showing that a comparison of a series of sections of the Coal-measures and Millstone series, taken from North Lancashire into Leicestershire and Warwickshire, shows that along this line the strata undergo a most remarkable amount of attenuation ; from which it may be inferred that they have been deposited according to a definite plan, depending on certain physical relations, and the distribution of land and sea during the Carboniferous Period. The following comparative sections will render this apparent :—

* In my paper "On the Thickness of the Carboniferous Rocks of the Pendle Hills, etc.," 'Journ. Geol. Soc. Lond.,' vol. xxiv, p. 319 (1868).

*Comparative Vertical Sections of Carboniferous Strata.**

—	Burnley District, North Lancashire, N.N.W.	Mottram District, East Cheshire.	North Staffordshire.	Leicestershire and Warwickshire, S.S.E.
	Feet.	Feet.	Feet.	Feet.
Coal-Measures ...	8,460	7,630	6,000	3,000
Millstone Grit series ...	5,500	2,500	500	} 100 to 300
Yoredale Series ...	4,670	2,000	2,300	
Total	18,630	12,130	8,800	3,100 to 3,300

From the above comparative sections it will be observed that the beds which attain to so grand a development in North Lancashire, have dwindled down to nearly one-sixth of their volume in Leicestershire, in proximity to the concealed Silurian Bank, as illustrated by fig. 23, p. 453.

A comparison of the combined thickness of coal in the several coal-fields also shows that to a great degree it undergoes a similar loss in thickness along the same tract of country; and as the occurrence of coal-seams in the Millstone Grit proves that, from time to time, there were land surfaces approximating to the sea level, at a period somewhat antecedent to that of the coal measures, the subsidence of this region must have amounted to several thousand feet vertical;† the vertical distance between the lowest and highest coal-seam showing approximately the actual amount of subsidence.

* 'Jour. Geol. Soc. Lond.,' vol. xxiv, p. 322. In the case of the Burnley section, where the coal-measures have been partially denuded, the section has been restored on the basis of that of South Lancashire.

† See observations of Sir C. Lyell on this head. 'Students' Manual of Geology,' edit. 1871, p. 378.

In the south of England, on the other hand, the coal-measures were deposited in greatest force toward the W.S.W., and become attenuated in an E.N.E. direction, as shown by a comparison of the sections in Glamorganshire and those of the Forest of Dean, which lay in original proximity to the southern slopes of the Silurian Bank, which stretched from Salop and Worcestershire into the eastern counties.

CHAPTER II

BRITISH PHYSICAL GEOLOGY.

Origin of Coal-Basins.—The British coal-fields now form a series of basins, some partially concealed by the sea, or by the overspread of newer formations; others visible all round their margins.

The visible coal-basins are: 1. South Wales; 2. Forest of Dean; 3. Burnley; 4. Ayrshire; 5. the Clyde Basin; 6. Mid-Lothian; 7. Tipperary and Kilkenny; 8. Leitrim (Connaught Coal-field).

The partly concealed basins are: 1. Somersetshire; 2. The Midland Basin, of which the Denbighshire, Shrewsbury, South Staffordshire, Warwickshire, Leicestershire and North Staffordshire Coal-fields form the marginal outcroppings, and of which the northern margin is concealed; 3. the South Lancashire and Cheshire Basin, of which the coal-fields of South Lancashire, Flintshire, and Cheshire form the marginal limits, the southern margin being concealed; 4. the Yorkshire, Derbyshire, and Notts Basin, of which the eastern margin is concealed; 5. the Northumberland and Durham Basin, of which the eastern and southern margins are concealed; and 6. the Cumberland Basin, of which the eastern and western margins are concealed. In Ireland, the coal-basin of Tyrone is partially concealed. The limits of these several basins in the British area are indicated on the general map of the coal-fields which accompanies this volume.

Basins not so Formed Originally.—It must not be supposed, however, that this basin-shaped arrangement of the Upper Carboniferous Strata was the original form in which the coal-fields were deposited, like so many lakes filled up with sediment and surrounded by hilly banks and barriers. Such an idea would be altogether erroneous. The basin-shaped structure is in every instance due to terrestrial movements acting along two systems of lines crossing each other transversely, accompanied and followed by denudation.

Original Distribution of Coal-Measures.—In order to follow the exceedingly interesting series of changes which have resulted in forming the British coal-basins, we shall first endeavour to ascertain to what extent, and along what limits, the Coal-measures were originally distributed. The accompanying map (Plate xii) is intended to illustrate both the areas covered originally by the coal-formation, and those destitute of that covering From this it will be seen that the coal area of Britain was distributed into two large tracts, one to the north, the other to the south of a band of country, stretching from North Wales, through Shropshire and Worcestershire, into the eastern counties. The Highlands of Scotland formed the limit to the northward for British Coal-measures, while the Highlands of Donegal, Mayo, and Galway formed the limit of the Irish Coal-measures. Through these great sheets of Carboniferous Rocks the Cumberland Mountains and a little of the Southern Uplands of Scotland protruded; while in Ireland the mountains of Wicklow and of Slieve Croob were also uncovered; but with these exceptions, we have the most conclusive evidence, that the coal-measures were continuous over the large tracts occupying the centre and

south of Ireland, the centre of Scotland, and the north and south of England.*

Terrestrial Movements at the Close of the Carboniferous Period.—At the close of the Carboniferous period, terrestrial movements took place over the whole of the British Islands and the neighbouring parts of the Continent of Europe, arising from the contraction of the earth's crust, due to the secular cooling thereof. These movements seem to have produced their most powerful effects upon the strata in the South and North of England, and are less discernible in the central part. The forces, however, acting in approximately north and south directions, took the form of lateral pressure, produced flexures in the Carboniferous strata at right angles thereto; in other words, along axes ranging nearly east and west.†

The arches (or anticlinal axes) rising into ridges and traversed by fissures, were subjected to denudation on a large scale, and considerable tracts of coal-measures were swept away and destroyed. One of these great arches, which itself included several minor folds,‡ was formed over the tract between the Yorkshire and Lancashire Coal-

* I have stated at length the evidence upon which this view is supported in the Memoir "On the Triassic and Permian Rocks of the Central Counties of England," Mem. Geol. Survey, p. 109 (1869). Also in my evidence before the Royal Coal-Commission (1871), Report, vol. ii; and at the meeting of the British Association, Liverpool, Trans., p. 74 (1870).

† In Lancashire the axes ranged along the line of the Pendle Ridge in an E.N.E. direction. In Yorkshire it was nearly east and west. In the South of England, Belgium, and France, nearly east and west.

‡ As shown by Prof. Phillips, "Geology of Yorkshire," and by the author, in his paper "On the Relative Ages of the Physical Features and Lines of Elevation of Lancashire and Yorkshire," Quart. Journ. Geol. Soc., vol. xxiv, p. 323.

fields on the south, and the Durham Coal-field on the north. The denudation which took place over this tract laid bare the Millstone grit and Yoredale rocks, and determined the boundaries of the coal-fields just named.

Another axis, or system of flexures, originated along the southern margin of the Carboniferous Limestone region of Derbyshire, extending westward along the valley of the River Dane, north of Congleton Edge, and, as I have shown on a former occasion, beneath the Triassic plain of Cheshire, emerging on the western side at the southern end of the Flintshire coal-field.* This lower Carboniferous axis forms, in my opinion, the southern border of the Lancashire and Cheshire Coal-basin, as stated above.†

South of England.—Other east and west flexures were also originated at this period, the most important being those of the south-west of England, shown by the longer axis of the South Wales Coal-field, and the uprising of the Carboniferous Limestone of the Mendips. These flexures doubtless extend under the Cretaceous rocks of the south of England, and are continued into the Franco-Belgian trough, and even across the Rhine into Westphalia.‡ All these leading flexures ranging east and west approximately, accompanied by the denudation of a vast amount of upper Carboniferous material, took place before the Permian strata were deposited ;§ and partly during it—

* See author's paper on "The Evidences of a Ridge of Lower Carboniferous Rocks beneath the Triassic Formation of the Plain of Cheshire," Journ. Geol. Soc. Lond., vol. xxv, p. 171.

† *Ibid.*, p. 180.

‡ As far as I am aware, I was the first to show the pre-Permian age of these east and west flexures of the S.W. of England in my paper, of which only an abstract is published in the Trans. Brit. Assoc. Liverpool, p. 75 (1870).

§ As there are no Permian strata in the South of England till we reach

in fact, during that long lapse of time which intervened between the close of the Carboniferous and the commencement of the Triassic period.

Distribution of Permian Strata.—Over the bent and denuded edges and surfaces of the Carboniferous strata the Permian rocks were distributed; those of central England, within a basin only a little more extended than that of the coal-measures themselves; the Permian beds of this tract being separated from those of the north of England by a ridge of lower Carboniferous land stretching from Charnwood Forest in Leicestershire, through Derbyshire, mid-Cheshire (along the concealed axis), into North Wales.* These Permian strata were thus deposited on Lower Carboniferous rocks over some parts of Yorkshire, North Lancashire, and Cumberland; while in South Lancashire, and parts of Yorkshire, Derbyshire, and Notts, they repose on various portions of the coal-formation.

Terrestrial Movements at the close of the Permian Period.—At the close of the Permian period, a new series of terrestrial movements took place, but *now* along lines ranging approximately north and south, and nearly at right angles to those which preceded them. These disturbances, accompanied by denudation acting chiefly along the arches or anticlinal axes, resulted in the disseverance of the coal-fields of Lancashire and Cheshire on one side, from those of Yorkshire, Derbyshire, and Notts on the other. It was

the valley of the Ex, or in S. Wales, it is probable the denudations went on over this area throughout the Permian period.

* See my reasons for this view in the paper already quoted, Journ. Geol. Soc., vol. xxv, p. 171, and chap. iii of the Memoirs "On the Triassic and Permian Rocks of the Central Counties," p. 28.

by this process that the Pennine chain or great central ridge, of the North of England was upheaved, and stripped of its covering of upper Carboniferous beds.* During the same period of disturbance the western limits of the Flintshire and Denbighshire Coal-field were determined; also the north and south axis along which the Durham Coal-field is inferred to rise and crop out beneath the sea, and which in its prolongation, southwards, is supposed to form the eastern limits of the Derbyshire Coal-basin. To the same period may also be referred the disseverance of the South Wales Coal-field from that of the Forest of Dean, and the sharp uprise of the Carboniferous strata along the east of the Somersetshire Coal-basin.

Basin-shape of Coal-fields due to the Intersection of these two Axes.—I have thus shown, briefly here, but more fully on other occasions, that the Carboniferous rocks owe their basin-shaped structure to the intersection, nearly at right angles, of these two systems of flexures, viz. :—

1. The earlier being pre-Permian, ranging along approximately east and west lines.

2. The latter being pre-Triassic, ranging along approximately north and south lines.

The intersection of these systems has caused numerous complications in the strata, which have been increased by disturbances of later date, while the disseverance of the basins from each other, has been the necessary consequence of the enormous amount of denudation which took place chiefly over the arches or anticlinals.

* That this great north and south upheaval took place before the deposition of the New Red Sandstone, is shown by the fact that the anticlinical fault which is the axis of the system of flexures passes beneath this formation at Leek, in Staffordshire, without in the least affecting it. See Maps of Geol. Survey.

On the other hand, the existing coal-basins lie in the synclinal troughs which were enclosed within the anticlinal arches.

Distribution of the Secondary, or Mesozoic, Strata.—It will be apparent, from what I have now stated, that the coal-basins received their form before the deposition of the New Red Sandstone, and the Secondary strata which were subsequently spread over the Carboniferous rocks, and served to protect the coal-fields from further denudation during a long lapse of geological time.

The manner in which the Triassic formations were themselves deposited deserves special observation, and bears directly on the question of the depth at which the coal-measures may be supposed to lie hidden over considerable tracts of country. This enquiry will form the subject of the next, and concluding, chapter.

CHAPTER III.

DISTRIBUTION OF THE MESOZOIC FORMATIONS.

South-easterly Attenuation of Strata.—Some years since I was led to make a comparison of the thickness of the Liassic and Triassic strata over various parts of England, taken from the accurately-measured sections of the Geological Survey; from which it was shown that they were originally distributed in such manner as to attain their greatest development toward the N.W. of England, and becoming attenuated towards the S.E.* This south-easterly attenuation of the Mesozoic strata will be apparent upon a comparison of the following sections, founded on actual admeasurements of the Government surveyors:—

—	Cheshire and Lancashire, N.W.	Stafford-shire, Midland.	Warwickshire, S.E.
	Feet.	Feet.	Feet.
New Red Sandstone or Trias—			
Keuper series	3,450	1,200	600
Bunter „	2,150	800	absent
Total	5,600	2,000	600

Here it will be observed that the attenuation of the

* See author's paper "On the South-Easterly Attenuation of the Lower Secondary Rocks of England," Journ. Geol. Soc., vol. xvi, p. 63 (1860).

Trias is so rapid, as to lead us to infer that, in its prolongation southward and eastward from Warwickshire, it does not extend far below the Chalk of Cambridge or Bedfordshire; although it would appear that the saline waters of St. Clement's Well at Oxford are, as Prof. Prestwich infers, derived from the Keuper Marls,* which (it will be observed above) are 600 feet thick near the borders of the Lias in Warwickshire.

In order to extend this comparison of development to the Lias, I shall now give the following comparative sections measured on several occasions at Bredon Cloud,† a hill at the N.W. of Gloucestershire, at the Cotteswold Hills near Winchcombe, and in the valley of the Evenlode at Stonesfield in Oxfordshire:—‡

——	Bredon Cloud, W.N.W.	Cotteswold Hills.	Stonesfield.	Oxford, S.E.
	Feet.	Feet.	Feet.	Feet.
Lias—				
Upper	880	200	10	200
Middle	250	150	15	
Lower	700	unknown	unknown	

The positions of the above localities lie in a relative direction from N.N.W. to S.S.E., nearly parallel to the

* The water from St. Clement's Well and borehole has been analysed by Mr. W. F. Donkin, who finds that it contains 493 grains per gallon of sulphates of soda and lime, and 748 of chloride of sodium. Such saline waters can only be derived from strata containing deposits of gypsum and rock-salt such as those of the New Red Marl formation; Proc. Ashmolean Soc., 1876.

† Hor. Sections, Geol. Survey, Sheet 60.

‡ "Geol. of Woodstock," Mem. Geol. Survey.

attenuation of the Triassic strata; and the determination by Prof. Prestwich of the existence of the Keuper Marls at a depth of only 420 feet under Oxford, below beds consisting of Oxford clay and Oolitic strata, shows that the attenuation of the Liassic beds is continuous at least thus far, the thickness of the three members of the formation being probably under 200 feet. This attenuation is no doubt partly due to the proximity of the shelving shore of Palæozoic land which underlies the Thames Valley, and in part, also, to the lessening of sediment in the Liassic sea itself. Upon the same principles we cannot but conclude that all the members of this formation originally overspread the plains of Lancashire and Cheshire in great force.*

The distribution of the Lower Permian strata is somewhat irregular, as they attain a thickness of 1,800 or 2,000 feet in Staffordshire and Warwickshire. Their development in Lancashire is variable.

Denudation of Mesozoic Strata.—It is, therefore, evident that the coal-measures of the central and north-western counties of England and Wales have been at one time buried beneath an enormous accumulation, amounting to several thousand feet, of Lower Mesozoic strata;† but it is still more worthy of observation that this *greatest* vertical development took place over those districts which are occupied by the rich coal-fields of the shires of Derby and York, Lancaster, Flint and Denbigh, Salop and Stafford; subsequently laid bare and rendered accessible by successive denudations. On the other hand, as we have seen, the

* Outliers of the Lower Lias occur in Cheshire and Cumberland, the remnants of a once widespread formation.

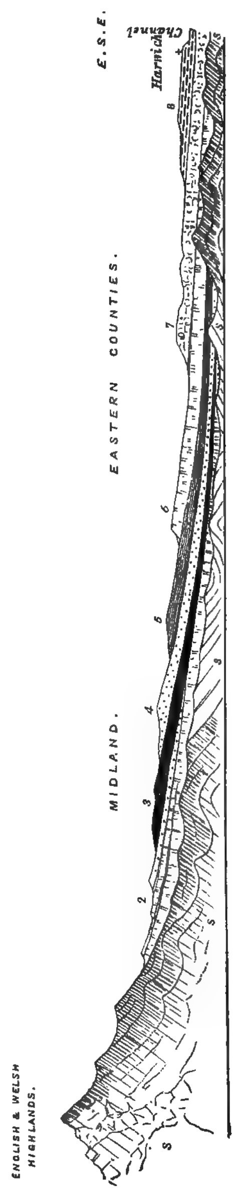
† The terms "Mesozoic" and "Secondary" are synonymous.

same post-Carboniferous strata became thinnest in the direction of the eastern counties;—over those districts where we believe the coal-measures have never been formed, and where, if penetrated, we should only reach Silurian and other rocks of an age anterior to the coal-formation. Thus we see that the various denudations have been more effectual in removing the Secondary strata over those parts of England where they originally overspread the coal-formation, than in those districts where they overlie rocks older than the coal-formation, and therefore destitute of that mineral.

The reader will be assisted in the comprehension of this subject by the following ideal section, which (minor details being omitted) is intended to illustrate the past and present distribution of these strata along a band of

Fig. 23.—IDEAL TRANSVERSE SECTION OF ENGLAND.

To illustrate the South-easterly attenuation of the Carboniferous and older Mesozoic Formations, as also the position of the Palæozoic Rocks under the Eastern Counties.



S. Silurian and Cambrian Rocks, forming the foundation for the more recent strata.
2. Lower Carboniferous Rocks.—3. Coal-measures.—4. Trias and Permian.—5. Lias.—6. Oolite.—7. Cretaceous.—8. Tertiary.

country stretching from N.W. to S.E. across Central England (Fig. 23).

The original foundation upon which rests the Carboniferous system is shown to be the Silurian and Cambrian rocks, as we find to be the case in Staffordshire and Leicestershire. The coal-measures are represented by a black bland, thickest towards the N.W., becoming thinner, and ultimately ending against the older rocks towards the S.E. The overlying formations are also represented, each outcropping in succession towards the N.W., in which direction they become most largely developed, and thinning away towards the S.E. It will be observed that the coal-formation comes to the surface where it is most productive, and that the overlying formations have been most unsparingly swept away where they have originally been deposited in greatest force.

Maximum Denudation towards the North-west.—Now this enormous denudation is a consequence of the upheaval which the formations have experienced at several periods; and as the strata on the whole dip towards the S.E., the elevatory forces have constantly acted with greatest energy in the direction of Wales, Westmoreland, and the north-western counties, and over the areas of several of the coal-fields, as also along an axis passing along the Pennine Chain; but they have all combined to produce one grand result, namely, the exposure of the Carboniferous rocks towards the N.W. of England.

Let us now regard this subject from another point of view. Supposing for a moment that the elevatory forces had acted with the greatest energy and effect along the S.E. of England so as to produce a general dip towards the N.W.; in other words, that the tilting of the strata had

taken place in a direction opposite to that actually existing;—what, let us enquire, would have been the result?

The answer is obvious; and we can state positively that, to all intents and purposes, England would have been almost as destitute of coal as she would have been had there been no Carboniferous formation. Let the reader glance at the ideal section (p. 453), and then imagine the dip reversed, and the denudation to have taken place *principally* towards the south-eastern side. Two results will at once present themselves. In the first place, the old pre-Carboniferous rocks—those of the Lower Palæozoic age—would occupy the right-hand side of the section, and on the left-hand side the coal-formation would nowhere reach the surface, as it would lie buried beneath an accumulative depth of Secondary rocks: for, upon it would be piled strata belonging to the Permian, Triassic, Liassic, and Oolitic systems, 6,000 to 8,000 feet in depth, rendering the coal inaccessible. Even supposing the elevation of the highlands of England and Wales to have occurred for the most part, as was undoubtedly the case, before the Carboniferous period, these mountains would have been enveloped and probably smothered in the embrace of the post-Carboniferous strata; and the highlands of England would have lain along the region now occupied by the Cretaceous and Tertiary rocks; that is, East Anglia. Under these conditions, Britain would have formed but an appendage of the European Continent. She could not, in all probability, have assumed that insular position which, through the favour of an overruling Providence, has rendered her "a shadow from the heat, a refuge from the storm" to the oppressed of Christendom.

I think, then, it must be evident that there is a fortunate

relationship between the original disposition of the rocks and their present distribution; we might even go further and assert that this has been highly advantageous to the commercial and manufacturing prosperity of the country; a condition of things which involves a long train of moral and social results. England might have become a rich commercial country like Holland, but never a manufacturing one as she is at the present day except under the physical conditions I have here but briefly pointed out. To the teleologist such facts will furnish new arguments; to all reflective minds they cannot fail to afford subjects of interest.

CHAPTER IV.

THE RESERVES OF COAL IN CONTINENTAL STATES.

In 1896 I received information through my friend the late Sir Charles Oppenheimer, H.B.M., Consul-General at Frankfort, that an enquiry into the coal resources of some of the Continental States had been made, and the results published in a short treatise by Geh. Bergrath R. Nasse in 1893.* This was interesting tidings, as showing that Continental States had been turning their attention, like ourselves, to the important question—how long their supplies of coal were destined to last; especially in view of the great increase in production which has taken place in recent years. I now proceed to give the reader a brief *résumé* of Herr Nasse's treatise, referring to the treatise itself for fuller details.

The author commences by the consideration of similar questions to those which have occupied ourselves, regarding the possible depths of coal-mining depending on temperature, quality, and thickness of the seams, and arrives at very similar conclusions.

With regard to increase of underground temperature he states that experience has shown that effective mining work cannot be carried on under a higher temperature than 40° C. (104° F.), in moist air, and 50° C. (122° F.) in very dry air; and estimating for the rate of increase in

* "Die Kohlenvorräthe der Europäischen Staaten," Berlin, 1893.

descending, he considers that mining will become impossible at more than 900 metres (in round numbers 3,000 feet) in damp, and 1,200 metres (4,000 feet) in dry air.* In the Ste. Henriette des Produits mine in Belgium, mining is carried on with much difficulty, owing to the high temperature, at a depth of 3,900 feet from the surface at present. The author does not apprehend much difficulty in working the seams, owing to the pressure of superincumbent strata at great depths; but the question of the least thickness of the workable seams of coal is one on which he expresses a very decided opinion. Given a seam of good quality, with good roof and floor, wages moderate, and price sufficient to give a fair profit, he does not think that seams under 2 feet in thickness will be worked at considerable depths; and as an illustration of his view he states that it has been found in Belgium that seams of 40 centimetres (about 1¼ foot), and 60 centimetres (about 2 feet) in the Saar and Rhur districts have been found not worth working.† The amount taken as an average for loss in working coal-mines is placed at 23 per cent., but this quantity is exclusive of the amount which has to be left untouched under large buildings, canals, and towns.

The enquiry into the coal-resources of Germany was commenced as far back as 1858 by Herr von Dechen, and published in a statistical work at the time.‡ Since then many years have elapsed, while the production of coal has

* It will be observed that this is the limit adopted in this work, see p. 267.

† This is confirmatory of the adoption of a 2-feet limit of thickness in estimating the resources of the British coal-fields, a limit I have always advocated as calculated to give a more reliable result in estimating the resources than that actually adopted by the Commissions of 1871 and 1904.

‡ "Statistik des zollvereinten und nördlichen Deutschlands."

enormously increased in all the German coal-basins, thus calling for newer and more reliable estimates.

In the summer of 1890, the Prussian Inspector of Mines (Oberbergämter) received from Freiherrn von Verlepsch the Commission to set on foot inquiries regarding the extent and resources of the different coal-basins of the German States, with other details regarding the area of workings, and quantities of coal at various depths down to 1,000 metres and over. The results have since been published, and almost simultaneously therewith were issued those of the Kingdom of Saxony; so that, as far as the more important coal-districts in Germany are concerned, the answer as to the duration of the coal-supplies can now be freshly attempted. This could be easily given were the annual production to remain constant, but it is otherwise with a production which has been annually increasing. The bearing of this production on the resources is then discussed for each State, and supplemented by tables of output—which need not detain us here—as those of more recent date have already been given.* The following is the general result of the resources of coal (steinkohle) in Germany :—

District.	Tons.
Ruhr	50,000,000,000
Saar	10,400,000,000
Aachen	1,800,000,000
Upper Silesia	45,000,000,000
Lower ,, ...	1,000,000,000
Kingdom of Saxony	400,000,000
Remaining small districts	400,000,000
Total	109,000,000,000

* *Ante*, pp. 383.

In brown coal the amount is 3,000 millions of tons. The whole of the above is contained within 1,000 metres in depth from the surface.

As regards France, M. A. de Lapparent estimated that for the output of 1890, there was sufficient coal to last for 700 or 800 years, which would represent from 17 to 19 milliard tons then remaining unexhausted. For Belgium no estimate of resources has yet been made; nor is this surprising, when we consider the remarkably contorted, faulted, and folded condition in which the coal-formation of that country has been left by nature.

THE END.

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